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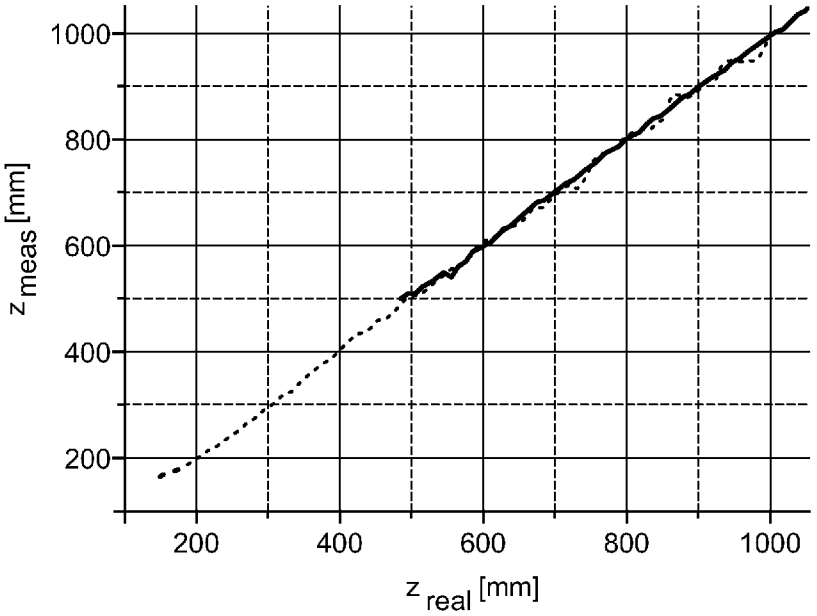
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(54) Title: DETECTOR FOR OPTICALLY DETECTING AT LEAST ONE OBJECT

FIG.3A



(57) Abstract: A detector (110) for determining a position of at least one object (112) is proposed. The detector (110) comprises: - at least one illumination source (114) adapted to generate at least one illumination light beam (116) for illuminating the object (112); a plurality of optical sensors (120), wherein each optical sensor (120) has at least one light sensitive area (121), wherein at least one of the optical sensors (120) is designed to generate at least one first sensor signal in response to an illumination of its respective light-sensitive area (121) by a reflection light beam (118) from the object (112), wherein the first sensor signal comprises at least one information of a first distance from the object (112) to the light sensitive area (121) of the optical sensor (120), wherein at least two of the optical sensors (120) are designed to generate at least one second sensor signal in response to the illumination of its respective light- sensitive area (121) by the reflection

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light beam (118), wherein each of the second sensor signal comprises at least one information about a beam profile of the reflection light beam (118) impinging on the light sensitive area (121); at least one evaluation device (128), wherein the evaluation device (128) is configured for determining at least one first longitudinal coordinate z_1 of the object (112) by evaluating the first sensor signal, wherein the evaluation device (128) is configured for determining at least one second longitudinal coordinate z_2 of the object (112) by evaluating a first combined signal Q from the second sensor signals.

Detector for optically detecting at least one object

Description

Field of the invention

The invention relates to a detector, a detector system and a method for determining a position of at least one object. The invention further relates to a human-machine interface for exchanging at least one item of information between a user and a machine, an entertainment device, a tracking system, a camera, a scanning system and various uses of the detector device. The devices, systems, methods and uses according to the present invention specifically may be employed for example in various areas of daily life, gaming, traffic technology, production technology, security technology, photography such as digital photography or video photography for arts, documentation or technical purposes, medical technology or in the sciences. Further, the invention specifically may be used for scanning one or more objects and/or for scanning a scenery, such as for generating a depth profile of an object or of a scenery, e.g. in the field of architecture, metrology, archaeology, arts, medicine, engineering or manufacturing. However, other applications are also possible.

Prior art

A large number of optical sensors and photovoltaic devices are known from the prior art. While photovoltaic devices are generally used to convert electromagnetic radiation, for example, ultraviolet, visible or infrared light, into electrical signals or electrical energy, optical detectors are generally used for picking up image information and/or for detecting at least one optical parameter, for example, a brightness.

A large number of optical sensors which can be based generally on the use of inorganic and/or organic sensor materials are known from the prior art. Examples of such sensors are disclosed in US 2007/0176165 A1, US 6,995,445 B2, DE 2501124 A1, DE 3225372 A1 or else in numerous other prior art documents. To an increasing extent, in particular for cost reasons and for reasons of large-area processing, sensors comprising at least one organic sensor material are being used, as described for example in US 2007/0176165 A1. In particular, so-called dye solar cells are increasingly of importance here, which are described generally, for example in WO 2009/013282 A1.

A large number of detectors for detecting at least one object are known on the basis of such optical sensors. Such detectors can be embodied in diverse ways, depending on the respective purpose of use. Examples of such detectors are imaging devices, for example, cameras and/or microscopes. High-resolution confocal microscopes are known, for example, which can be used in particular in the field of medical technology and biology in order to examine biological samples with high optical resolution. Further examples of detectors for optically detecting at least one object are distance measuring devices based, for example, on propagation time methods of corresponding optical signals, for example laser pulses. Further examples, of detectors for opti-

cally detecting at least one object are edge detection detectors using depth from focus technologies. However, edge detection may be only possible at relatively short distances from the object to the detector. Further examples of detectors for optically detecting at least one object are confocal detectors by means of which distance measurement can be carried out. However such detectors may require mechanical movement of detector components to ensure that the object is in a focus of an optical system of the detector. Further examples of detectors for optically detecting objects are triangulation systems, for example using laser triangulation, by means of which distance measurements can likewise be carried out. Kurt Konolige et al., A Low-Cost Laser Distance Sensor, 2008 IEEE International Conference on Robotics and Automation, Pasadena, CA, USA, May 19-23, 2008, discuss competing technologies using triangulation for planar laser distance sensor (LDS). Structured line devices use a light stripe laser and offset camera to determine range to a set of points. Because the laser energy is spread over a line, it is difficult to achieve accurate range, especially in the presence of ambient light, or with darker objects. Point scan devices for 3D scanning of small objects typically use a scanning mirror to direct a point laser beam and redirect the laser return to an optical receiver. Such devices cannot be miniaturized, and their cost and mechanical fragility will remain high. Centroid point modules typically use position-sensitive devices (PSD). These devices measure the centroid of all light impinging on their surface. Although modulation techniques can be used to offset some of the effects of ambient light, PSDs do not perform well unless the laser spot has a very strong reflection, limiting their use to ranges of a meter or less. Pixel-based point modules search the pixel with maximum signal intensity to determine the position of the light spot on the sensor. Typically CMOS line arrays are used for detection. Konolige et al. introduce a low-cost version of a Pixel-based point module.

In WO 2012/110924 A1, the content of which is herewith included by reference, a detector for optically detecting at least one object is proposed. The detector comprises at least one optical sensor. The optical sensor has at least one sensor region. The optical sensor is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region. The sensor signal, given the same total power of the illumination, is dependent on a geometry of the illumination, in particular on a beam cross section of the illumination on the sensor area. The detector furthermore has at least one evaluation device. The evaluation device is designed to generate at least one item of geometrical information from the sensor signal, in particular at least one item of geometrical information about the illumination and/or the object.

WO 2014/097181 A1, the full content of which is herewith included by reference, discloses a method and a detector for determining a position of at least one object, by using at least one transversal optical sensor and at least one optical sensor. Specifically, the use of sensor stacks is disclosed, in order to determine a longitudinal position of the object with a high degree of accuracy and without ambiguity.

WO 2015/024871 A1, the full content of which is herewith included by reference, discloses an optical detector, comprising:

- at least one spatial light modulator being adapted to modify at least one property of a light beam in a spatially resolved fashion, having a matrix of pixels, each pixel being controllable to individually modify the at least one optical property of a portion of the light beam passing the pixel;
- at least one optical sensor adapted to detect the light beam after passing the matrix of pixels of the spatial light modulator and to generate at least one sensor signal;
- at least one modulator device adapted for periodically controlling at least two of the pixels with different modulation frequencies; and
- at least one evaluation device adapted for performing a frequency analysis in order to determine signal components of the sensor signal for the modulation frequencies.

US 4,767,211 discloses an apparatus for and a method of measuring a boundary surface of a sample in which a ratio of the light quantity of a part of reflected light from a sample which travels in the vicinity of the optical axis of the reflected light, to the light quantity of another part of the reflected light which is directed to a position deviating from the optical axis by a predetermined distance is used to accurately measure a boundary surface of a sample. Since the accuracy of measurement is increased by using the above ratio, light capable of passing through the sample can be used as incident light. Thus, a deep hole in the surface of the sample and a void such as an air bubble in a living being sample, which cannot be measured by the prior art, can be measured very accurately.

WO 2014/198629 A1, the full content of which is herewith included by reference, discloses a detector for determining a position of at least one object, comprising:

- at least one optical sensor, the optical sensor being adapted to detect a light beam propagating from the object towards the detector, the optical sensor having at least one matrix of pixels; and
- at least one evaluation device, the evaluation device being adapted to determine a number N of pixels of the optical sensor which are illuminated by the light beam, the evaluation device further being adapted to determine at least one longitudinal coordinate of the object by using the number N of pixels which are illuminated by the light beam.

Further, generally, for various other detector concepts, reference may be made to WO 2014/198626 A1, WO 2014/198629 A1 and WO 2014/198625 A1, the full content of which is herewith included by reference. Further, referring to potential materials and optical sensors which may also be employed in the context of the present invention, reference may be made to European patent applications EP 15 153 215.7, filed on January 30, 2015, EP 15 157 363.1, filed on March 3, 2015, EP 15 164 653.6, filed on April 22, 2015, EP 15177275.3, filed on July 17, 2015, EP 15180354.1 and EP 15180353.3, both filed on August 10, 2015, and EP 15 185 005.4, filed on September 14, 2015, EP 15 196 238.8 and EP 15 196 239.6, both filed on November 25, 2015, EP 15 197 744.4, filed on December 3, 2015, the full content of all of which is herewith also included by reference.

Further, reference may be made to detector concepts comparing signals of at least two different sources for determining a position of an object. Thus, as an example, reference may be made to EP 16155834.1, EP 16155835.8 or EP 16155845.7, all filed on February 16, 2016, the full disclosure of which is herewith included by reference.

Further, P. Bartu, R. Koeppe, N. Arnold, A. Neulinger, L. Fallon, and S. Bauer, *Conformable large-area position-sensitive photodetectors based on luminescence collecting silicone waveguides*, J. Appl. Phys. 107, 123101 (2010), describe a kind of position sensitive detector (PSD) device which might be suitable for large areas and on curved surfaces. This kind of PSD device is based on a planar silicone waveguide with embedded fluorescent dyes used in conjunction with small silicon photodiodes, which may be arranged in a regular pattern, such as at the edges of the device or distributed over the device. Impinging laser light may be absorbed by the dye in the PSD device and re-emitted as fluorescence light at a larger wavelength. Due to a predominantly isotropic emission from the fluorescent dye molecules, the re-emitted light may at least partially coupled into the planar silicone waveguide and directed to the silicon photodiodes, wherein the light signals may be detected via the silicon photodiodes. By using algorithms as known from global positioning systems (GPS), the position of light spots may be determined. For further details and for information about later developments which are related to this kind of PSD device reference may be made to WO 2009/105801 A1, WO 2010/118409 A2, WO 2010/118450 A1, WO 2013/090960 A1, WO 2013/ 116883 A1, and WO2015/081362 A1. However, this kind of PSD device is not adapted for 3D-sensing such that further development is required to provide an optical detector well-suited for this purpose.

Despite the advantages implied by the above-mentioned devices and detectors, several technical challenges remain. Thus, generally, a need exists for detectors for detecting a position of an object in space which is both reliable and may be manufactured at low cost. Specifically, a need exists for 3D-sensing concepts. Various known concepts are at least partially based on using so-called FiP sensors, such as several of the above-mentioned concepts. Therein, as an example, large area sensors may be used, in which the individual sensor pixels are significantly larger than the light spot and which are fixed to a specific size. Still, large area sensors in many cases are inherently limited in the use of the FiP measurement principle, specifically in case more than one light spot is to be investigated simultaneously.

A further challenge using FiP detectors is detector area or active area. Typically, for distance measurements, a large active area of the detector is used or even is required. This area, however, may cause noise problems, specifically when the tetralateral conductivity concept is employed to build a PSD. This often results in poor signal-to-noise-ratios and slow detector response times due to the large capacitance in conjunction with the series resistance of the detector. A further challenge using FiP detectors is cost of manufacturing. Thus, in many cases, typical FiP sensors are expensive, as compared to e.g. conventional Si-based photodiodes. Further, the evaluation of the measurement results of measurements using FiP-sensors remains an issue, specifically in case the total power of a light beam is unknown. In case a plurality of FiP-sensors is used, located at different positions along an axis of propagation of the light beam, a

range of measurement typically is limited to the range in between the two positions of the sensors. Further, many FiP-detectors show a luminance dependency which renders the evaluation of the measurement result more difficult, and, additionally, FiP-measurements in many cases are dependent on a target spot size.

US 2011/222075 A1 describes an optical position detection device which includes: a light source adapted to emit at least one detection light beam toward one side in a Z-axis direction; a first detector having a light receiving section directed to the one side in the Z-axis direction; a second detector located at a position on the one side in the Z-axis direction, the position being distant from the light source and the first detector, and having a light receiving section directed to the one side in the Z-axis direction; and a position derivation section adapted to derive a position of a object located in a first space between the first detector and the second detector and a position of a object located in a second space on the one side of the second detector in the Z-axis direction based on a light receiving result in the first detector and the second detector.

US 5,125,735 A describes a distance measuring device which has a light source for emitting a plurality of light beams in a plurality of directions, and a light receiving lens having a plurality of optical axes for receiving the plurality of light beams reflected from objects in said plurality of directions. Light receiving apparatus is provided for receiving the reflected light beams passing through said light receiving lens and providing an output corresponding to distances to the object. The light receiving lens has (1) a central portion with a thickness D, a focal length fa, and a refractive index phi A, and (2) a second portion adjacent said central portion. Surfaces of said central and second portions closest to said light receiving apparatus comprising one spherical surface having a refractive power phi R. the central and second portions being disposed to satisfy the following conditions: 0.4<D/fA<1.5, and -0.05< phi R/ phi A<0.15, phi A>0.

US 4,548,504 A describes a device for determining the real or the virtual distance of a source of light from a measuring plane. Such devices are preferably employed in position detectors in which light produced by a light source is caused to impinge on the surface of the object to be measured, said light being reflected from said surface towards a photodetector. The light emitted by the light source is imaged at different points on said detector, this depending on the position of the surface of the object to be measured, it thus being possible to draw a conclusion as regards the position of said object. The imaging system and the position-sensitive detector form a rotationally symmetrical arrangement.

WO 2013/144649 A1 describes a position detection system for detecting the three dimensional position of at least one target. Each target is configured to act as a retro-reflector for light incident from any direction. At least one light emitter illuminates the at least one target and at least one detector is provided for detecting and taking measurements of light retro-reflected from a target. A processor for processing measurements taken by each detector is described to determine the three dimensional position of the at least one target.

Referring to concepts comparing sensor signals generated by at least two different sources such as at least two different optical sensors, one technical challenge remains a reduction of cost of the overall system and, specifically, of the optical sensors. Thus, in many concepts, special optical sensors have to be used, having a dedicated design and placement, which typically requires setting up an expensive optoelectronic semiconductor manufacturing process and a complex assembly scheme.

Further challenges for 3D sensing methods result from environmental influences causing multiple reflections, biasing light sources or reflective measurement objects. For example, time of flight systems are abundant and cheap three-dimensional sensing systems but have difficulties in reflective environments and with low target reflectivity. Furthermore, time of flight systems have the drawback of minimum and maximum sensing distances due to periodicity of the sensing signal.

Problem addressed by the invention

It is therefore an object of the present invention to provide devices and methods facing the above-mentioned technical challenges of known devices and methods. Specifically, it is an object of the present invention to provide devices and methods which reliably may determine a position of an object in space, preferably with a low technical effort and with low requirements in terms of technical resources and cost.

Summary of the invention

This problem is solved by the invention with the features of the independent patent claims. Advantageous developments of the invention, which can be realized individually or in combination, are presented in the dependent claims and/or in the following specification and detailed embodiments.

As used in the following, the terms “have”, “comprise” or “include” or any arbitrary grammatical variations thereof are used in a non-exclusive way. Thus, these terms may both refer to a situation in which, besides the feature introduced by these terms, no further features are present in the entity described in this context and to a situation in which one or more further features are present. As an example, the expressions “A has B”, “A comprises B” and “A includes B” may both refer to a situation in which, besides B, no other element is present in A (i.e. a situation in which A solely and exclusively consists of B) and to a situation in which, besides B, one or more further elements are present in entity A, such as element C, elements C and D or even further elements.

Further, it shall be noted that the terms “at least one”, “one or more” or similar expressions indicating that a feature or element may be present once or more than once typically will be used only once when introducing the respective feature or element. In the following, in most cases, when referring to the respective feature or element, the expressions “at least one” or “one or

more" will not be repeated, non-withstanding the fact that the respective feature or element may be present once or more than once.

Further, as used in the following, the terms "preferably", "more preferably", "particularly", "more particularly", "specifically", "more specifically" or similar terms are used in conjunction with optional features, without restricting alternative possibilities. Thus, features introduced by these terms are optional features and are not intended to restrict the scope of the claims in any way. The invention may, as the skilled person will recognize, be performed by using alternative features. Similarly, features introduced by "in an embodiment of the invention" or similar expressions are intended to be optional features, without any restriction regarding alternative embodiments of the invention, without any restrictions regarding the scope of the invention and without any restriction regarding the possibility of combining the features introduced in such a way with other optional or non-optional features of the invention.

In a first aspect of the present invention a detector for determining a position of at least one object is disclosed. As used herein, the term "object" refers to a point or region emitting at least one light beam. The light beam may originate from the object, such as by the object and/or at least one illumination source integrated or attached to the object emitting the light beam, or may originate from a different illumination source, such as from an illumination source directly or indirectly illuminating the object, wherein the light beam is reflected or scattered by the object. As used herein, the term "position" refers to at least one item of information regarding a location and/or orientation of the object and/or at least one part of the object in space. Thus, the at least one item of information may imply at least one distance between at least one point of the object and the at least one detector. As will be outlined in further detail below, the distance may be a longitudinal coordinate or may contribute to determining a longitudinal coordinate of the point of the object. Additionally or alternatively, one or more other items of information regarding the location and/or orientation of the object and/or at least one part of the object may be determined. As an example, additionally, at least one transversal coordinate of the object and/or at least one part of the object may be determined. Thus, the position of the object may imply at least one longitudinal coordinate of the object and/or at least one part of the object. Additionally or alternatively, the position of the object may imply at least one transversal coordinate of the object and/or at least one part of the object. Additionally or alternatively, the position of the object may imply at least one orientation information of the object, indicating an orientation of the object in space.

The detector comprises:

- at least one illumination source adapted to generate at least one illumination light beam for illuminating the object;
- a plurality of optical sensors, wherein each optical sensor has at least one light sensitive area, wherein at least one of the optical sensors is designed to generate at least one first sensor signal in response to an illumination of its respective light-sensitive area by a reflection light beam from the object, wherein the first sensor signal com-

prises at least one information about a first distance from the object to the light sensitive area of the optical sensor,
wherein at least two of the optical sensors are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam, wherein each of the second sensor signals comprises at least one information about a beam profile of the reflection light beam impinging on the light sensitive area;

- at least one evaluation device, wherein the evaluation device is configured for determining at least one first longitudinal coordinate z_1 of the object by evaluating the first sensor signal, wherein the evaluation device is configured for determining at least one second longitudinal coordinate z_2 of the object by evaluating a first combined signal Q from the second sensor signals.

As used herein, an "illumination source" refers to a device adapted to generate at least one illumination light beam for illuminating the object. The illumination source may emit light in at least one of: the ultraviolet spectral range, preferably in the range of 200 nm to 380 nm; the visible spectral range (380 nm to 780 nm); the infrared spectral range, preferably in the range of 780 nm to 3.0 micrometers, more preferably in the part of the near infrared region, specifically in the range of 700 nm to 1000 nm. For example, the at least one illumination source is adapted to emit light in the visible spectral range, preferably in the range of 500 nm to 780 nm, most preferably at 650 nm to 750 nm or at 690 nm to 700 nm. For example, the at least one illumination source is adapted to emit light in the infrared spectral range. Other options, however, are feasible.

The illumination source may comprise an artificial illumination source, in particular at least one laser and/or laser source, in particular a pulsed laser source, and/or at least one incandescent lamp and/or at least one semiconductor light source, for example, at least one light-emitting diode, in particular a pulsed light-emitting diode, in particular an organic and/or inorganic light-emitting diode. Various types of lasers may be employed, such as semiconductor lasers. Additionally or alternatively, non-laser light sources may be used, such as LEDs and/or light bulbs. The illumination source may be adapted to generate and/or to project a cloud of points, for example the illumination source may comprise one or more of at least one digital light processing (DLP) projector, at least one LCoS projector, at least one spatial light modulator; at least one diffractive optical element; at least one array of light emitting diodes; at least one array of laser light sources.

The illumination source may be adapted to generate pulsed illumination. The illumination source may be adapted to generate at least one light pulse. As used herein, the term "light pulse" or "pulsed illumination" refers to a light beam limited in time. The light pulse may have a predefined length or time duration, for example in the nanoseconds range. For example, the illumination source may be adapted to generate pulses with a pulse length of less than a nanosecond, such as a tenth of a nanosecond, up to a tenth of a second. The illumination source may

be adapted to periodically generate the light pulse. For example, the illumination source may be adapted to generate the light pulse with a frequency of 10 Hz to 10 GHz.

The illumination source may be adapted to generate a pulsed light beam. For example, the illumination source may be adapted to generate a continuous illumination light beam and the detector may comprise at least one interruption device adapted to interrupt the illumination, in particular periodically. The interruption device may comprise at least one shutter and/or a beam chopper or some other type of mechanical or electronical periodic beam interrupting device, for example comprising at least one interrupter blade or interrupter wheel, which preferably rotates at constant speed and which can thus periodically interrupt the illumination. By way of example, the at least one interruption device can also be wholly or partly integrated into the illumination source. Various possibilities are conceivable.

The detector may be configured such that the illuminating light beam propagates from the detector towards the object along an optical axis of the detector. For this purpose, the detector may comprise at least one reflective element, preferably at least one prism, for deflecting the illuminating light beam onto the optical axis. The illuminating light beam generally may be parallel to the optical axis or tilted with respect to the optical axis, e.g. including an angle with the optical axis. As an example, the illuminating light beam, such as the laser light beam, and the optical axis may include an angle of less than 10°, preferably less than 5° or even less than 2°. Other embodiments, however, are feasible. Further, the illuminating light beam may be on the optical axis or off the optical axis. As an example, the illuminating light beam may be parallel to the optical axis having a distance of less than 10 mm to the optical axis, preferably less than 5 mm to the optical axis or even less than 1 mm to the optical axis or may even coincide with the optical axis.

The information about the first distance may comprise at least one information of a time of flight the illumination light beam has traveled from the illumination source to the object and the reflection light beam has traveled from the object to the light sensitive area of the optical sensor. As used herein, the term “first distance” refers to the at least one first longitudinal coordinate. The optical sensor adapted to generate the first sensor signal may be designed as time-of-flight detector. The time-of-flight detector may be selected from the group consisting of: at least one pulsed time-of-flight detector; at least one phase modulated time-of-flight detector; at least one direct time-of-flight detector; at least one indirect time-of-flight detector. For example, the pulsed time-of-flight detector may be at least one range gated imager and/or at least one direct time-of-flight imager. For example the phase modulated time-of-flight detector may be at least one RF-modulated light source with at least one phase detector. The optical sensor may be adapted to determine a time delay between emission of the illumination light beam by the illumination source and receipt of the reflection light beam.

For example, the optical sensor adapted to generate the first sensor signal may be designed as pulsed time-of-flight detector. The detector may comprise the at least one interruption device, such as at least one shutter element, adapted to generate a pulsed light beam. The optical sen-

sor may be adapted to store the first sensor signal dependent on receiving time of the reflection light beam in a plurality of time windows, in particular subsequent time windows. The optical sensor may be adapted to store dependent on receiving time of the reflection light beam the generated first sensor signal in at least one first time window and/or in at least one second time window. The first and second time windows may be correlated with the opening and closure of the interruption device. Duration of first and second time windows may be pre-defined. For example, the first sensor signal may be stored in the first time window during opening of the interruption device, whereas during closure of the interruption device the first sensor signal may be stored in the second time window. Other durations of time windows are thinkable. The first and the second time window may comprise information about background, signal height and signal shift.

For example, the optical sensor adapted to generate the first sensor signal may be designed as direct time-of-flight imager. The direct time-of-flight imager may comprise the at least one illumination source adapted to generate at least one single laser pulse. The single laser pulse may be reflected back from the object onto the optical sensor. The optical sensor may comprise at least one photo diode, for example at least one Avalanche Photo Diode (APD), such as at least one Si APD, or such as at least one InGaAs APD, or at least one PIN photo detector array, or at least one Single-Photon Avalanche Photodiode (SPAD), adapted to image the reflection light beam. The direct time-of flight imager may be adapted to image at least one image comprising spatial and temporal data.

For example, the optical sensor adapted to generate the first sensor signal may be designed as phase modulated time-of-flight modulator. The phase modulated time-of-flight modulator may be adapted to measure a difference in phase, in particular phase shift, by determining a correlated signal, for example by multiplying a received signal, i.e. of the reflection light beam, with the emitted signal, i.e. the illumination light beam. A DC component of the correlated signal may comprise an information about the difference in phase. The evaluation device may be adapted to determine the second longitudinal coordinate of the object from the phase difference. For example, the illumination source and the optical sensor adapted to generate the first sensor signal may be designed as RF-modulated light source with at least one phase detector. The illumination source may comprise, for example, at least one LED and/or at least one laser. The illumination source may comprise at least one modulation device adapted to modulate the light beam having a pre-defined phase shift. For example, the modulation device may comprise at least one radio frequency module. The radio frequency module may be adapted to modulate the illumination beam with an RF carrier. The optical sensor may be adapted to determine a phase shift of the reflective light beam impinging on the optical sensor.

The optical sensor may be designed as and/or may comprise at least one time-of-flight (ToF) pixel. Preferably, the detector may comprise at least two optical sensors, wherein each optical sensor is designed as and/or comprises at least one ToF pixel. For example, the detector, in particular the optical sensor, may comprise a quadrant diode adapted to generate the first sen-

sor signal. For example, the detector, in particular the optical sensor, may comprise at least one pixelated ToF-imager.

As used herein, an "optical sensor" generally refers to a light-sensitive device for detecting a light beam, such as for detecting an illumination and/or a light spot generated by at least one light beam. As further used herein, a "light-sensitive area" generally refers to an area of the optical sensor which may be illuminated externally, by the at least one light beam, in response to which illumination the at least one sensor signal is generated. The light-sensitive area may specifically be located on a surface of the respective optical sensor. Other embodiments, however, are feasible. As used herein, "a plurality of optical sensors" refers to two and more optical sensors such as three, four, five, ten or even more than ten optical sensors. Preferably, the detector comprises exactly two optical sensors. As used herein, the term "a plurality of optical sensors each having at least one light sensitive area" refers to configurations with individual optical sensors each having one light sensitive area and to configurations with combined optical sensors having at least two light sensitive areas. Thus, the term "optical sensor" furthermore refers to a light-sensitive device configured to generate one output signal, whereas, herein, a light-sensitive device configured to generate two or more output signals, for example at least one CCD and/or CMOS device, is referred to as two or more optical sensors. As will further be outlined in detail below, each optical sensor may be embodied such that precisely one light-sensitive area is present in the respective optical sensor, such as by providing precisely one light-sensitive area which may be illuminated, in response to which illumination precisely one uniform sensor signal is created for the whole optical sensor. Thus, each optical sensor may be a single area optical sensor. The use of the single area optical sensors, however, renders the setup of the detector specifically simple and efficient. Thus, as an example, commercially available photo-sensors, such as commercially available silicon photodiodes, each having precisely one sensitive area, may be used in the set-up. Other embodiments, however, are feasible. Thus, as an example, an optical device comprising two, three, four or more than four light-sensitive areas may be used which is regarded as two, three, four or more than four optical sensors in the context of the present invention. As an example, the optical device may comprise a matrix of light-sensitive areas. Thus, as an example, the optical sensors may be part of or constitute a pixelated optical device. As an example, the optical sensors may be part of or constitute at least one CCD and/or CMOS device having a matrix of pixels, each pixel forming a light-sensitive area.

As further used herein, a "sensor signal" generally refers to a signal generated by an optical sensor in response to the illumination by the light beam. Specifically, the sensor signal may be or may comprise at least one electrical signal, such as at least one analogue electrical signal and/or at least one digital electrical signal. More specifically, the sensor signal may be or may comprise at least one voltage signal and/or at least one current signal. More specifically, the sensor signal may comprise at least one photocurrent. Further, either raw sensor signals may be used, or the detector, the optical sensor or any other element may be adapted to process or preprocess the sensor signal, thereby generating secondary sensor signals, which may also be used as sensor signals, such as preprocessing by filtering or the like.

As used herein, the term “first sensor signal” refers to a sensor signal which comprises information of a first distance from the object to the light sensitive area of the respective sensor. The first sensor signal may comprise at least one information about a time-of-flight the illumination light beam has traveled from the illumination source to the object and the reflection light beam has traveled from the object to the light sensitive area of the optical sensor. As used herein, the term “information of a time of flight” refers to information about the time, in particular a time period, the illumination light beam has travelled from the illumination source to the object and/or the reflection light has travelled from the object to the optical sensor.

At least two of the optical sensors are designed to generate each at least one second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam. As used herein, the term “second sensor signal” refers to a sensor signal comprising at least one information about a beam profile of the light beam impinging on the light sensitive area. Each of the second sensor signals may comprise at least one intensity information of the reflection light beam impinging on the light sensitive area. As used herein, the term “intensity information” refers to information about intensity of the reflection light beam at a location of the optical sensors and/or information about a beam profile of the reflection light beam. In particular, each of the second sensor signals may comprise at least one information about a second distance from the object to the light sensitive area of the optical sensor. The information about the first distance and the information about the second distance may refer to information, in particular distances, determined and/or derived by different measurement methods. For example, the information about the first distance may refer to time-of-flight information, whereas the information about the second distance may refer to beam profile information. The first distance and the second distance may be different.

At least one of the optical sensors is designed to generate the at least one first sensor signal. At least two of the optical sensors are designed to generate the at least one second sensor signal. In particular, each optical sensor of the two optical sensors designed to generate the at least one second sensor signal is adapted to generate at least one second sensor signal. All or some optical sensors of the plurality of optical sensors may be designed to generate the first sensor signal and the second sensor signal. For example, the detector may comprise two optical sensors. A first optical sensor may be designed to generate and/or produce the first sensor signal and the second sensor signal. A second optical sensor may be designed to generate and/or produce the second sensor signal. Additionally or alternatively, each of the optical sensors may be designed to generate both the first sensor signal and second sensor signal.

The light-sensitive areas specifically may be oriented towards the object. As used herein, the term “is oriented towards the object” generally refers to the situation that the respective surfaces of the light-sensitive areas are fully or partially visible from the object. Specifically, at least one interconnecting line between at least one point of the object and at least one point of the respective light-sensitive area may form an angle with a surface element of the light-sensitive area which is different from 0°, such as an angle in the range of 20° to 90°, preferably 80 to 90°

such as 90°. Thus, when the object is located on the optical axis or close to the optical axis, the light beam propagating from the object towards the detector may be essentially parallel to the optical axis. As used herein, the term "essentially perpendicular" refers to the condition of a perpendicular orientation, with a tolerance of e.g. ±20° or less, preferably a tolerance of ±10° or less, more preferably a tolerance of ±5° or less. Similarly, the term "essentially parallel" refers to the condition of a parallel orientation, with a tolerance of e.g. ±20° or less, preferably a tolerance of ±10° or less, more preferably a tolerance of ±5° or less.

The object may be or may comprise at least one reflective element such as a reflective surface and/or at least one reflector adapted to generate the at least one reflection light beam in response to the illumination with the illumination light beam of the reflective element.

The illumination light beam may propagate from the illumination source to the object. The object may be adapted to generate a reflection light beam. The reflection light beam may propagate from the object towards the detector. The illumination light beam may originate from an illumination source directly illuminating the object, wherein the light beam is reflected or scattered by the object and, thereby, is at least partially directed towards the detector. The illumination source, as an example, may be or may comprise an illumination source integrated into the detector. The illumination source may be fixedly installed within the detector and/or may be fixedly connected with the detector. For example, the illumination source may be adapted to illuminate the object, for example, by directing a light beam towards the object, which reflects the light beam. Additionally, the object may be adapted to generate and/or to emit the at least one light beam. The illumination source may be or may comprise at least one multiple beam light source. For example, the light source may comprise at least one laser source and one or more diffractive optical elements (DOEs).

As used herein, the term "ray" generally refers to a line that is perpendicular to wavefronts of light which points in a direction of energy flow. As used herein, the term "beam" generally refers to a collection of rays. In the following, the terms "ray" and "beam" will be used as synonyms. As further used herein, the term "light beam" generally refers to an amount of light, specifically an amount of light traveling essentially in the same direction, including the possibility of the light beam having a spreading angle or widening angle. The light beam may have a spatial extension. Specifically, the light beam may have a non-Gaussian beam profile. The beam profile may be selected from the group consisting of a trapezoid beam profile; a triangle beam profile; a conical beam profile. The trapezoid beam profile may have a plateau region and at least one edge region. As used herein, the term "beam profile" generally refers to a transverse intensity profile of the light beam. In addition, the term "beam profile" relates to a spatial distribution, in particular in at least one plane perpendicular to the propagation of the light beam, of an intensity of the light beam. The light beam specifically may be a Gaussian light beam or a linear combination of Gaussian light beams, as will be outlined in further detail below. Other embodiments are feasible, however. For example, the detector may comprise at least one transfer device adapted to one or more of adjusting, defining and determining the beam profile, in particular a shape of the beam profile.

The optical sensors may be sensitive in one or more of the ultraviolet, the visible or the infrared spectral range. Specifically, the optical sensors may be sensitive in the visible spectral range from 500 nm to 780 nm, most preferably at 650 nm to 750 nm or at 690 nm to 700 nm. Specifically, the optical sensors may be sensitive in the near infrared region. Specifically, the optical sensors may be sensitive in the part of the near infrared region where silicon photodiodes are applicable specifically in the range of 700 nm to 1000 nm. The optical sensors, specifically, may be sensitive in the infrared spectral range, specifically in the range of 780 nm to 3.0 micrometers. For example, the optical sensors each, independently, may be or may comprise at least one element selected from the group consisting of a photodiode, a photocell, a photoconductor, a phototransistor or any combination thereof. For example, the optical sensors may be or may comprise at least one element selected from the group consisting of a CCD sensor element, a CMOS sensor element, a photodiode, a photocell, a photoconductor, a phototransistor or any combination thereof. Any other type of photosensitive element may be used. As will be outlined in further detail below, the photosensitive element generally may fully or partially be made of inorganic materials and/or may fully or partially be made of organic materials. Most commonly, as will be outlined in further detail below, one or more photodiodes may be used, such as commercially available photodiodes, e.g. inorganic semiconductor photodiodes.

The detector may comprise at least one transfer device. The term “transfer device”, also denoted as “transfer system”, may generally refer to one or more optical elements which are adapted to modify the light beam, such as by modifying one or more of a beam parameter of the light beam, a width of the light beam or a direction of the light beam. The transfer device may be adapted to guide the light beam onto the optical sensors. The transfer device specifically may comprise one or more of: at least one lens, for example at least one lens selected from the group consisting of at least one focus-tunable lens, at least one aspheric lens, at least one spheric lens, at least one Fresnel lens; at least one diffractive optical element; at least one concave mirror; at least one beam deflection element, preferably at least one mirror; at least one beam splitting element, preferably at least one of a beam splitting cube or a beam splitting mirror; at least one multi-lens system.

As used herein, the term “focal length” of the transfer device refers to a distance over which incident collimated rays which may impinge the transfer device are brought into a “focus” which may also be denoted as “focal point”. Thus, the focal length constitutes a measure of an ability of the transfer device to converge an impinging light beam. Thus, the transfer device may comprise one or more imaging elements which can have the effect of a converging lens. By way of example, the transfer device can have one or more lenses, in particular one or more refractive lenses, and/or one or more convex mirrors. In this example, the focal length may be defined as a distance from the center of the thin refractive lens to the principal focal points of the thin lens. For a converging thin refractive lens, such as a convex or biconvex thin lens, the focal length may be considered as being positive and may provide the distance at which a beam of collimated light impinging the thin lens as the transfer device may be focused into a single spot. Additionally, the transfer device can comprise at least one wavelength-selective element, for example at least one optical filter. Additionally, the transfer device can be designed to impress a pre-

defined beam profile on the electromagnetic radiation, for example, at the location of the sensor region and in particular the sensor area. The abovementioned optional embodiments of the transfer device can, in principle, be realized individually or in any desired combination.

The transfer device may have an optical axis. In particular, the detector and the transfer device have a common optical axis. As used herein, the term “optical axis of the transfer device” generally refers to an axis of mirror symmetry or rotational symmetry of the lens or lens system. The optical axis of the detector may be a line of symmetry of the optical setup of the detector. The detector comprises at least one transfer device, preferably at least one transfer system having at least one lens. The transfer system, as an example, may comprise at least one beam path, with the elements of the transfer system in the beam path being located in a rotationally symmetrical fashion with respect to the optical axis. Still, as will also be outlined in further detail below, one or more optical elements located within the beam path may also be off-centered or tilted with respect to the optical axis. In this case, however, the optical axis may be defined sequentially, such as by interconnecting the centers of the optical elements in the beam path, e.g. by interconnecting the centers of the lenses, wherein, in this context, the optical sensors are not counted as optical elements. The optical axis generally may denote the beam path. Therein, the detector may have a single beam path along which a light beam may travel from the object to the optical sensors, or may have a plurality of beam paths. As an example, a single beam path may be given or the beam path may be split into two or more partial beam paths. In the latter case, each partial beam path may have its own optical axis. The optical sensors may be located in one and the same beam path or partial beam path. Alternatively, however, the optical sensors may also be located in different partial beam paths.

The transfer device may constitute a coordinate system, wherein a longitudinal coordinate l is a coordinate along the optical axis and wherein d is a spatial offset from the optical axis. The coordinate system may be a polar coordinate system in which the optical axis of the transfer device forms a z-axis and in which a distance from the z-axis and a polar angle may be used as additional coordinates. A direction parallel or antiparallel to the z-axis may be considered a longitudinal direction, and a coordinate along the z-axis may be considered a longitudinal coordinate l. Any direction perpendicular to the z-axis may be considered a transversal direction, and the polar coordinate and/or the polar angle may be considered a transversal coordinate.

The optical sensors may be positioned off focus. As used herein, the term “focus” generally refers to one or both of a minimum extend of a circle of confusion of the light beam, in particular of at least one light beam emitted from one point of the object, caused by the transfer device or a focal length of the transfer device. As used herein, the term “circle of confusion” refers to a light spot caused by a cone of light rays of the light beam focused by the transfer device. The circle of confusion may depend on a focal length f of the transfer device, a longitudinal distance from the object to the transfer device, a diameter of an exit pupil of the transfer device, a longitudinal distance from the transfer device to the light sensitive area, a distance from the transfer device to an image of the object. For example, for Gaussian beams, a diameter of the circle of confusion may be a width of the Gaussian beam. In particular, for a point like object situated or

placed at infinite distance from the detector the transfer device may be adapted to focus the light beam from the object into a focus point at the focal length of the transfer device. For non-point like objects situated or placed at infinite distance from the detector the transfer device may be adapted to focus the light beam from at least one point of the object into a focus plane at the focal length of the transfer device. For point like objects not situated or placed at infinite distance from the detector, the circle of confusion may have a minimum extend at least at one longitudinal coordinate. For non-point like objects not situated or placed at infinite distance from the detector, the circle of confusion of the light beam from at least one point of the object may have a minimum extend at least at one longitudinal coordinate. As used herein, the term "positioned off focus" generally refers to a position other than the minimum extend of a circle of confusion of the light beam caused by the transfer device or a focal length of the transfer device. In particular, the focal point or minimum extend of the circle of confusion may be at a longitudinal coordinate l_{focus}, whereas the position of each of the optical sensors may have a longitudinal coordinate l_{sensor} different from l_{focus}. For example, the longitudinal coordinate l_{sensor} may be, in a longitudinal direction, arranged closer to the position of the transfer device than the longitudinal coordinate l_{focus} or may be arranged further away from the position of the transfer device than the longitudinal coordinate l_{focus}. Thus, the longitudinal coordinate l_{sensor} and the longitudinal coordinate l_{focus} may be situated at different distances from the transfer device. For example, the optical sensors may be spaced apart from the minimum extend of the circle of confusion in longitudinal direction by ± 2% of focal length, preferably by ± 10% of focal length, most preferably ± 20% of focal length. For example, at a focal length of the transfer device may be 20mm and the longitudinal coordinate l_{sensor} may be 19,5 mm, i.e. the sensors may be positioned at 97,5% focal length, such that l_{sensor} is spaced apart from the focus by 2,5% of focal length.

The optical sensors may be arranged such that the light-sensitive areas of the optical sensors differ in at least one of: their longitudinal coordinate, their spatial offset, or their surface areas. Each light-sensitive area may have a geometrical center. As used herein, the term "geometrical center" of an area generally may refer to a center of gravity of the area. As an example, if an arbitrary point inside or outside the area is chosen, and if an integral is formed over the vectors interconnecting this arbitrary point with each and every point of the area, the integral is a function of the position of the arbitrary point. When the arbitrary point is located in the geometrical center of the area, the integral of the absolute value of the integral is minimized. Thus, in other words, the geometrical center may be a point inside or outside the area with a minimum overall or sum distance from all points of the area.

For example, each geometrical center of each light-sensitive area may be arranged at a longitudinal coordinate $l_{center,i}$, wherein i denotes the number of the respective optical sensor. In the case of the detector comprising precisely two optical sensors and in the case of the detector comprising more than two optical sensors, the optical sensors may comprise at least one first optical sensor, wherein the first optical sensor, in particular the geometrical center, being arranged at a first longitudinal coordinate $l_{center,1}$, and at least one second optical sensor, wherein the second optical sensor, in particular the geometrical center, being at a second longitudinal coordinate $l_{center,2}$, wherein the first longitudinal coordinate and the second longitudinal coordi-

nate differ. For example, the first optical sensor and the second optical sensor may be located in different planes which are offset in a direction of the optical axis. The first optical sensor may be arranged in front of the second optical sensor. Thus, as an example, the first optical sensor may simply be placed on the surface of the second optical sensor. Additionally or alternatively, the first optical sensor may be spaced apart from the second optical sensor, for example, by no more than five times the square root of a surface area of the first light-sensitive area. Additionally or alternatively, the first optical sensor may be arranged in front of the second optical sensor and may be spaced apart from the second optical sensor by no more than 50 mm, preferably by no more than 15 mm. Relative distance of the first optical sensor and second optical sensor may depend, for example, on focal length or object distance.

The longitudinal coordinates of the optical sensors may also be identical, as long as one of the above-mentioned conditions is fulfilled. For example, the longitudinal coordinates of the optical sensors may be identical, but the light-sensitive areas may be spaced apart from the optical axis and/or the surface areas differ.

Each geometrical center of each light-sensitive area may be spaced apart from the optical axis of the transfer device, such as the optical axis of the beam path or the respective beam path in which the respective optical sensor is located. The distance, in particular in transversal direction, between the geometrical center and the optical axis is denoted by the term “spatial offset” In the case of the detector comprising precisely two optical sensors and in the case of the detector comprising more than two optical sensors, the optical sensors may comprise at least one first optical sensor being spaced apart from the optical axis by a first spatial offset and at least one second optical sensor being spaced apart from the optical axis by a second spatial offset, wherein the first spatial offset and the second spatial offset differ. The first and second spatial offsets, as an example, may differ by at least a factor of 1.2, more preferably by at least a factor of 1.5, more preferably by at least a factor of two. The spatial offsets may also be zero or may assume negative values, as long as one of the above-mentioned conditions is fulfilled.

As used herein, the term “surface area” generally refers to both of a shape and a content of at least one light-sensitive area. In the case of the detector comprising precisely two optical sensors and in the case of the detector comprising more than two optical sensors, the optical sensors may comprise at least one first optical sensor having a first surface area and at least one second optical sensor having a second surface area. In the case of the detector comprising more than two optical sensors, e.g. a sensor element comprising a matrix of optical sensors, a first group of optical sensors or at least one of the optical sensors of the matrix may form a first surface area, wherein a second group of optical sensors or at least one other optical sensor of the matrix may form a second surface area. The first surface area and the second surface area may differ. In particular, the first surface area and the second surface area may not be congruent. Thus, the surface area of the first optical sensor and the second optical sensor may differ in one or more of the shape or content. For example, the first surface area may be smaller than the second surface area. As an example, both the first surface area and the second surface area may have the shape of a square or of a rectangle, wherein side lengths of the square or

rectangle of the first surface area are smaller than corresponding side lengths of the square or rectangle of the second surface area. Alternatively, as an example, both the first surface area and the second surface area may have the shape of a circle, wherein a diameter of the first surface area is smaller than a diameter of the second surface area. Again, alternatively, as an example, the first surface area may have a first equivalent diameter, and the second surface area may have a second equivalent diameter, wherein the first equivalent diameter is smaller than the second equivalent diameter. The surface areas may be congruent, as long as one of the above-mentioned conditions is fulfilled.

The optical sensors, in particular the light-sensitive areas, may overlap or may be arranged such that no overlap between the optical sensors is given.

As further used herein, the term “evaluation device” generally refers to an arbitrary device adapted to perform the named operations, preferably by using at least one data processing device and, more preferably, by using at least one processor and/or at least one application-specific integrated circuit. Thus, as an example, the at least one evaluation device may comprise at least one data processing device having a software code stored thereon comprising a number of computer commands. The evaluation device may provide one or more hardware elements for performing one or more of the named operations and/or may provide one or more processors with software running thereon for performing one or more of the named operations.

The evaluation device is configured for determining the at least one first longitudinal coordinate z_1 of the object by evaluating the first sensor signal. As used herein, the term “first longitudinal coordinate” refers to a longitudinal coordinate derived from the first sensor signal. As described above, the illumination light source may be adapted to periodically generate at least one light pulse. The detector may be adapted to generate the first longitudinal sensor signal for each period.

The evaluation device may be adapted to determine in which pulse period the first sensor signal was generated using the second longitudinal coordinate. The detector may be adapted to uniquely assign to which period the ToF-signal refers to by using the second sensor signals. Both, the first sensor signal and the second sensor signals, may be non-monotonous functions of the longitudinal coordinate z_{real}. Thus, the longitudinal coordinate may not be uniquely determined from one of the first sensor signal or the second sensor signals alone and a measurement range may not be restricted to a longitudinal range in which the signals are unique functions of z_{real}.

The term “measurement range” generally refers to a range from the object to the detector in which determination of the longitudinal coordinate is possible. The term “longitudinal range” generally refers to a range from the object to the detector in which unique determination of the longitudinal coordinate is possible. Below and/or above certain distances from the object to the detector a determination of the longitudinal coordinate may not be possible. For example, time-of-flight measurements are not possible below a certain distance from the object to the detector,

possibly due to the minimum measurement time of the internal clock. Furthermore, in time-of-flight measurements the sensor signal may be unique within a longitudinal period, but the sensor signal may be the same in case integer multiples of the longitudinal period are added such that the determined longitudinal coordinate may be non-unique. Thus, the same first sensor signal will be obtained for a distance z_1 and a distance z_1+nz_{1p}, where n is an integer denoting the longitudinal period and z_{1p} is the longitudinal period of the first sensor signal, wherein the distances z_1 and z_1+nz_{1p} are within the measurement range. As used herein, the term "longitudinal period" refers to partitions of a period, in particular a distance range, in which the longitudinal coordinate can be unambiguously determined from the first sensor signal. Non-unique longitudinal coordinates may be denoted as relative longitudinal coordinates and the unique longitudinal coordinates may be denoted as absolute longitudinal coordinates.

If both the first sensor signal F_1 and the second sensor signals F_2 are available, it may be possible to uniquely determine the longitudinal coordinate and to extend the longitudinal range, as long as each signal pair (F_1,F_2) corresponds to a unique distance and vice versa. In particular, if a unique signal pair (F_1,F_2) exists for each longitudinal coordinate and vice versa, the evaluation device may be adapted to determine the unique combined longitudinal coordinate by
(1) selecting at least one first selected signal such as the first sensor signal and/or the second sensor signals and determining non-unique first longitudinal coordinates;
(2) selecting a second selected signal such as the first combined signal Q and/or the other sensor signal, which was not selected in step (1), and determining non-unique second longitudinal coordinates;
(3) determining whether one of the non-unique first longitudinal coordinates and the non-unique second longitudinal coordinates match up to a predetermined tolerance threshold;
(4) setting a combined unique longitudinal coordinate to be a matching longitudinal coordinate.

In step (1) and step (2), signals may be selected in the given order or may be performed in a different order. For example, in step (1) the first sensor signal may be selected and in step (2) the first combined signal Q may be selected. In another example, in step (1) the second senor signals may be selected, the at least one first combined signal may be determined and the non-unique first longitudinal sensor signal may be determined therefrom. In step (2), the first sensor signal may be selected.

Additionally or alternatively to step (4), the evaluation device may be adapted to output an error signal in case no matching coordinates are found and/or to output an error signal in case more than one matching coordinates are found. Additionally or alternatively, the signal pairs and their corresponding longitudinal coordinates may be stored in a look-up table. Additionally or alternatively, the signal pairs and their corresponding longitudinal coordinates may be approximated or described by an analytical function which is evaluated to find the longitudinal coordinate corresponding to a given signal pair.

The evaluation device may comprise at least two memory elements. As used herein, the term "memory element" refers to a device adapted to store information. The evaluation device may

be adapted to receive and to store information provided by the optical sensors, for example the at least one first sensor signal. Such information may comprise raw sensor data and/or processed sensor data. For example, the memory element may be adapted to store information for further evaluation by the evaluation device. The memory element may be a volatile or non-volatile memory element.

As described above, the optical sensor may be designed as and/or may comprise at least one ToF pixel. The detector may comprise at least two switches. Each of the switches may be connected to the optical sensor adapted to generate the first sensor signal, for example by at least one connector. In particular, each of the switches may be connected to the ToF pixel. The switches are adapted to provide the first sensor signal to one of the memory elements. In particular, the switches may be adapted to let, dependent on receiving time of the reflection light beam, the generated first sensor signal pass through one of the switches. For example, the first sensor signal may pass one of the switches during opening of the interruption device, whereas during closure of the interruption device the first sensor signal may pass the other switch. Each of the switches may be controlled by a control signal having a pulse length identical to a pulse length of a light pulse generated by the illumination source. The control signal of one of the switches may be delayed. For example, the delay may correspond to the pulse length of the light pulse. The evaluation device may be adapted to sample and/or store depending on the delay a first part, or fraction, of the first sensor signal through a first switch in a first memory element and the other, second part, or fraction, of the first sensor signal through a second switch in a second memory element. The evaluation device may be adapted to determine the first longitudinal coordinate by evaluating the first part and second part of the first sensor signal. The evaluation device may be adapted to determine the first longitudinal coordinate z_1 by

$$z_1 = \frac{1}{2} \cdot c \cdot t_0 \cdot \frac{S1_2}{S1_1 + S1_2} + z_0;$$

wherein c is the speed of light, t_0 is the pulse length of the illumination light beam, z_0 is a distance offset often determined by the resolution of the time measurement, and $S1_1$ and $S1_2$ are the first part and second part of the first sensor signal, respectively.

The evaluation device is configured for determining at least one second longitudinal coordinate z_2 of the object by evaluating a first combined signal Q from the second sensor signals. As used herein, the term “second longitudinal coordinate” refers to a longitudinal coordinate derived from the second sensor signal. The expression “first” and “second” longitudinal coordinate are used as designations and do not relate to an order of determination of the first and second longitudinal coordinates. As used herein, the term “first combined signal Q” refers to a signal which is generated by combining the sensor signals, in particular by one or more of dividing the sensor signals, dividing multiples of the sensor signals or dividing linear combinations of the sensor signals. The evaluation device may be configured for deriving the first combined signal Q by one or more of dividing the sensor signals, dividing multiples of the sensor signals, dividing linear combinations of the sensor signals. The evaluation device may be configured for using at least one predetermined relationship between the first combined signal Q and the second longitudinal coordinate z_2 for determining the second longitudinal coordinate z_2. For example, the evaluation device is configured for deriving the first combined signal Q by

$$Q(z_O) = \frac{\iint_{A_1} E(x,y;z_2)\,dxdy}{\iint_{A_2} E(x,y;z_2)\,dxdy}$$

wherein x and y are transversal coordinates, A1 and A2 are areas of the beam profile at the sensor position, and $E(x,y,z_2)$ denotes the beam profile given at the object distance z_o. Area A1 and area A2 may differ. In particular, A1 and A2 are not congruent. Thus, A1 and A2 may differ in one or more of the shape or content. The beam profile may be a cross section of the light beam. The beam profile may be selected from the group consisting of a trapezoid beam profile; a triangle beam profile; a conical beam profile and a linear combination of Gaussian beam profiles. Generally the beam profile is dependent on luminance $L(z_2)$ and beam shape $S(x,y;z_2)$, $E(x,y;z_2) = L \cdot S$. Thus, by deriving the quotient signal it may allow determining the second longitudinal coordinate independent from luminance.

Each of the second sensor signals may comprise at least one information of at least one area of the beam profile of at least one beam profile of the reflection light beam. As used herein, the term "area of the beam profile" generally refers to an arbitrary region of the beam profile at the sensor position used for determining the first combined signal Q. The light-sensitive regions may be arranged such that one of the second sensor signals comprises information of a first area of the beam profile and the other one of the second sensor signals comprises information of a second area of the beam profile. The first area of the beam profile and second area of the beam profile may be one or both of adjacent or overlapping regions. The first area of the beam profile and the second area of the beam profile may be not congruent in area.

The evaluation device may be configured to determine and/or to select the first area of the beam profile and the second area of the beam profile. The first area of the beam profile may comprise essentially edge information of the beam profile and the second area of the beam profile may comprise essentially center information of the beam profile. The beam profile may have a center, i.e. a maximum value of the beam profile and/or a center point of a plateau of the beam profile and/or a geometrical center of the light spot, and falling edges extending from the center. The second region may comprise inner regions of the cross section and the first region may comprise outer regions of the cross section. As used herein, the term "essentially center information" generally refers to a low proportion of edge information, i.e. proportion of the intensity distribution corresponding to edges, compared to a proportion of the center information, i.e. proportion of the intensity distribution corresponding to the center. Preferably the center information has a proportion of edge information of less than 10 %, more preferably of less than 5%, most preferably the center information comprises no edge content. As used herein, the term "essentially edge information" generally refers to a low proportion of center information compared to a proportion of the edge information. The edge information may comprise information of the whole beam profile, in particular from center and edge regions. The edge information may have a proportion of center information of less than 10 %, preferably of less than 5%, more

preferably the edge information comprises no center content. At least one area of the beam profile may be determined and/or selected as second area of the beam profile if it is close or around the center and comprises essentially center information. At least one area of the beam profile may be determined and/or selected as first area of the beam profile if it comprises at least parts of the falling edges of the cross section. For example, the whole area of the cross section may be determined as first region. The first area of the beam profile may be area A2 and the second area of the beam profile may be area A1.

The edge information may comprise information relating to a number of photons in the first area of the beam profile and the center information may comprise information relating to a number of photons in the second area of the beam profile. The evaluation device may be adapted for determining an area integral of the beam profile. The evaluation device may be adapted to determine the edge information by integrating and/or summing of the first area. The evaluation device may be adapted to determine the center information by integrating and/or summing of the second area. For example, the beam profile may be a trapezoid beam profile and the evaluation device may be adapted to determine an integral of the trapezoid. Further, when trapezoid beam profiles may be assumed, the determination of edge and center signals may be replaced by equivalent evaluations making use of properties of the trapezoid beam profile such as determination of the slope and position of the edges and of the height of the central plateau and deriving edge and center signals by geometric considerations.

Additionally or alternatively, the evaluation device may be adapted to determine one or both of center information or edge information from at least one slice or cut of the light spot. This may be realized, for example, by replacing the area integrals in the first combined signal Q by line integrals along the slice or cut. For improved accuracy, several slices or cuts through the light spot may be used and averaged. In case of an elliptical spot profile, averaging over several slices or cuts may result in an improved distance information.

The evaluation device may be configured to derive the first combined signal Q by one or more of dividing the edge information and the center information, dividing multiples of the edge information and the center information, dividing linear combinations of the edge information and the center information. Thus, essentially, photon ratios may be used as the physical basis of the method.

The evaluation device may be configured to determine the at least one second longitudinal coordinate z_2 of the object by using at least one known, determinable or predetermined relationship between the second sensor signals. In particular, the evaluation device is configured to determine the at least one coordinate z of the object by using at least one known, determinable or predetermined relationship between the first combined signal derived from the second sensor signals and the second longitudinal coordinate.

Thus, the evaluation device specifically may be configured for deriving the first combined signal Q by dividing the second sensor signals, by dividing multiples of the second sensor signals or

by dividing linear combinations of the second sensor signals. As an example, Q may simply be determined as

$$Q = s_1/s_2$$

or

$$Q = s_2/s_1,$$

with s_1 denoting one of the second sensor signals and s_2 denoting the other one of the second sensor signals. Additionally or alternatively, Q may be determined as

$$Q = a \cdot s_1/b \cdot s_2$$

or

$$Q = b \cdot s_2/ a \cdot s_1,$$

with a and b being real numbers which, as an example, may be predetermined or determinable. Additionally or alternatively, Q may be determined as

$$Q = (a \cdot s_1 + b \cdot s_2) / (c \cdot s_1 + d \cdot s_2),$$

with a, b, c and d being real numbers which, as an example, may be predetermined or determinable. As a simple example for the latter, Q may be determined as

$$Q = s_1 / (s_1 + s_2).$$

Other first combined signals are feasible.

Typically, in the setup described above, Q is a monotonous function of the second longitudinal coordinate of the object and/or of the size of the light spot such as the diameter or equivalent diameter of the light spot. Thus, as an example, specifically in case linear optical sensors are used, the quotient $Q=s_1/s_2$ is a monotonously decreasing function of the size of the light spot. Without wishing to be bound by this theory, it is believed that this is due to the fact that, in the preferred setup described above, both the second sensor signals s_1 and s_2 decrease as a square function with increasing distance to the light source, since the amount of light reaching the detector decreases. Therein, however, one of the second sensor signal s_1 decreases more rapidly than the other one of the second signals s_2, since, in the optical setup as used in the experiments, the light spot in the image plane grows and, thus, is spread over a larger area. The quotient of the second sensor signals, thus, continuously decreases with increasing diameter of the light beam or diameter of the light spot on the light-sensitive areas. The quotient, further, is mainly independent from the total power of the light beam, since the total power of the

light beam forms a factor both in the first sensor signal and in the second sensor signal. Consequently, the quotient Q may form a secondary signal which provides a unique and unambiguous relationship between the second sensor signals and the size or diameter of the light beam. Since, on the other hand, the size or diameter of the light beam is dependent on a distance between the object, from which the light beam propagates towards the detector, and the detector itself, i.e. dependent on the longitudinal coordinate of the object, a unique and unambiguous relationship between the second sensor signals and the longitudinal coordinate may exist. For the latter, reference e.g. may be made to one or more of the above-mentioned prior art documents, such as WO 2014/097181 A1. The predetermined relationship may be determined by analytical considerations, such as by assuming a linear combination of Gaussian light beams, by empirical measurements, such as measurements measuring second sensor signals or a secondary signal derived thereof as a function of the longitudinal coordinate of the object, or both.

The evaluation device is configured for determining the second longitudinal coordinate by evaluating the first combined signal Q. The evaluation device may be configured for using at least one predetermined relationship between the first combined signal Q and the second longitudinal coordinate. The predetermined relationship may be one or more of an empiric relationship, a semi-empiric relationship and an analytically derived relationship. The evaluation device may comprise at least one data storage device for storing the predetermined relationship, such as a lookup list or a lookup table.

The first combined signal Q may be determined by using various means. As an example, a software means for deriving the first combined signal, a hardware means for deriving the first combined signal, or both, may be used and may be implemented in the evaluation device. Thus, the evaluation device, as an example, may comprise at least one divider, wherein the divider is configured for deriving the first combined signal. The divider may fully or partially be embodied as one or both of a software divider or a hardware divider.

The optical sensors specifically may be arranged linearly in one and the same beam path of the detector. As used herein, the term “linearly” generally refers to that the sensors are arranged along one axis. Thus, as an example, the first and second optical sensors both may be located on an optical axis of the detector. Specifically, the first and second optical sensors may be arranged concentrically with respect to an optical axis of the detector.

The detector may be adapted to determine the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2 subsequently or simultaneously. The detector may be adapted to determine the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2 independent from each other.

The evaluation device may be adapted to use one of the first signal and the second sensor signals to estimate a range of the longitudinal coordinate and the other one of the first sensor signal and the second sensor signals to determine the longitudinal position within the range. The

evaluation device may be adapted to perform a coarse determination of the range, such as a minimum and maximum distance between the object and the detector. For example, the evaluation device may be adapted to provide an estimation about a maximum distance and/or minimum distance between the object and the detector by evaluating the first sensor signal. In a subsequent evaluation step, the evaluation device may be adapted to perform a precise determination of the longitudinal coordinate of the object by using the second sensor signals in consideration of the range determined from the first sensor signal. Alternatively, the second signals may be used for providing estimation about a maximum distance and/or minimum distance between the object and the detector and the precise determination of the longitudinal coordinate may be performed by using the first sensor signal in consideration of the range determined from the second sensor signals. This may allow enhance reliability of determination of the longitudinal coordinate. Further, this may increase the total measurement range of the detector.

The detector may comprise two optical sensors. The light sensitive areas of the optical sensors may differ in size. The light-sensitive area of the first optical sensor may be smaller than the light-sensitive area of the second optical sensor. As used therein, the term “is smaller than” refers to the fact that the surface area of the light-sensitive area of the first optical sensor is smaller than the surface area of the light-sensitive area of the second optical sensor. For example, the first optical sensor has a small light-sensitive area of 1.5 mm x 1.5 mm and the second optical sensor has a large light-sensitive area of 1.5 mm x 4.1 mm. The first optical sensor and the second optical sensor may be a photodiode having two light sensitive areas. The first optical sensor and the second optical sensor may be arranged asymmetrically. For example, the first optical sensor and the second optical sensor may be asymmetric dual-elements of a PIN-photodiode available as Hamamatsu® S9345. As an example, both the light-sensitive area of the first optical sensor and the light-sensitive area of the second optical sensor may have the shape of a square or of a rectangle, wherein side lengths of the square or rectangle of the light-sensitive area of the first optical sensor are smaller than corresponding side lengths of the square or rectangle of the light-sensitive area of the second optical sensor. Alternatively, as an example, both the light-sensitive area of the first optical sensor and the light-sensitive area of the second optical sensor may have the shape of a circle, wherein a diameter of the light-sensitive area of the first optical sensor is smaller than a diameter of the light-sensitive area of the second optical sensor. Again, alternatively, as an example, the light-sensitive area of the first optical sensor may have a first equivalent diameter, and the light-sensitive area of the second optical sensor may have a second equivalent diameter, wherein the first equivalent diameter is smaller than the second equivalent diameter. A gap may be provided between the light sensitive-area of the first optical sensor and the light sensitive-area of the second optical sensor. Specifically, the gap between the light sensitive-area of the first optical sensor and the light sensitive-area of the second optical sensor may be from 0.1 µm to 30 µm in a direction perpendicular to the optical axis, more preferably, from 0.1 µm - 21 µm.

The detector may comprise at least one slow measurement channel and at least one fast measurement channel. The slow measurement channel may comprise at least one of the first optical sensor and the second optical sensor and the fast measurement channel may comprise

the first optical sensor only. As outlined above, the light-sensitive area of the first optical sensor may be smaller than the light-sensitive area of the second optical sensor. The slow measurement channel may be adapted to measure the sensor signals with a measurement frequency of 1 – 500.000 Hz, whereas the fast measurement channel may measure the sensor signals with a measurement frequency higher than the slow measurement channel, such as with a measurement frequency of 10.000 – 100.000.000 Hz. In general, sensors with small light-sensitive areas have lower capacities and thus, can be read out faster than larger light-sensitive areas. Each of the first optical sensor and the second optical sensor may be configured for generating the second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam. Each of the second sensor signals may comprise the information about the beam profile of the reflection light beam impinging on the respective light sensitive area. The evaluation device may be configured for determining the second longitudinal coordinate z_2 of the object by evaluating the first combined signal Q from the second sensor signals. The first optical sensor may be configured for generating the first sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam from the object. The first sensor signal may comprise the information about the first distance from the object to the light sensitive area of the optical sensor. The information about the first distance may comprise the information of the time of flight the illumination light beam has traveled from the illumination source to the object.

The illumination source may be arranged having an offset with respect to the optical axis of the detector. The illumination source and the light-sensitive areas of the first optical sensor and the second optical sensor may be arranged such that in a far field only the first optical sensor is illuminated by the light beam travelling from the object to the detector. The illumination source and the light-sensitive areas of the first optical sensor and the second optical sensor may be arranged such that in a near field both of the light-sensitive areas of the first optical sensor and the second optical sensor are illuminated by the light beam travelling from the object to the detector. As used herein, the terms “near field” and “far field“ refer to distance between the optical sensors and the object, wherein near field refers to objects close to the optical sensors and far field refers to object at a greater distance. The near field and the far field may be defined by parameters of the optical system, such as the baseline, BL, which may be absolute value of the distance of the exit pupil of the illumination source from the optical axis, the gap position, g, which may be the absolute value of the distance of the mean of the gap between the at least two light sensitive areas from the optical axis, and the light sensitive area position, b, which is the absolute value of the distance of the light sensitive areas from the lens, parallel to the optical axis. The near field may be defined as the distance range parallel to the optical axis from the detector up to a distance of less than $10 \cdot BL \cdot b/g$, preferably up to a distance of less than $5 \cdot BL \cdot b/g$, more preferably up to a distance of less than $3 \cdot BL \cdot b/g$. The far field may be defined as the distance range parallel to the optical axis from a distance of at least $0.1 \cdot BL \cdot b/g$, preferably from a distance of at least $1 \cdot BL \cdot b/g$, more preferably from a distance of at least

$2.9 \cdot BL \cdot b/g$, up to a distance beyond the measurement range of the detector such as up to a distance of 10 km, preferably up to a distance of 1 km, more preferably up to a distance of 100 m. Preferably the near field and the far field overlap by a distance range of at least $0.01 \cdot BL \cdot b/g$, preferably by a distance range of at least $0.1 \cdot BL \cdot b/g$, more preferably by a distance range of at least $1.0 \cdot BL \cdot b/g$.

In case the illumination source is arranged with an offset with respect to the optical axis such as an offset in an x direction, a center of the light spot on the light-sensitive areas of the respective optical sensor may shift perpendicular to the optical axis, for example in the x direction by Δx. The shift of the center may depend on the distance Δz between the optical sensors and the object. The shift of the center per object distance, Δx/Δz, may be larger for the near field compared to the shift of the center per object distance for the far field. Thus, for distance measurements in the near field a large light-sensitive area, such as the second optical sensor and/or both optical sensors, may be advantageous such that the light spot is situated in a broad measurement range on the detector. For distance measurements in the far field a small detector may be suitable. For distance measurements using time-of-flight techniques a smaller detector may be advantageous since small detectors generally imply lower capacities and thus, can be read out faster than larger detectors. As outlined above, a PIN-photodiode available as Hamamatsu® S9345 may be used which combines one large and one small light-sensitive area having a small gap in between. The larger light-sensitive area may be used for generating at least one of the second sensor signals for determining the first combined signal Q and may be, specifically, advantageous in the near field. For example, the first combined signal may be determined by dividing the second sensor signals generated by the first and second optical sensors. The optical detector having the larger light-sensitive area may be used only for determining the second longitudinal coordinate z2. The optical sensor having the smaller light-sensitive area may be used for both time-of-flight measurement and determining the second longitudinal coordinate z2. Using the larger light-sensitive area only for determining the second longitudinal coordinate z2 but not for time-of-flight measurement allows to design a slower and low-priced measurement channel compared to the fast measurement channel for both time-of-flight measurement and determining the second longitudinal coordinate z2 from the first combined signal. The optical sensors and the illumination source may be arranged such that in far field only the optical sensor having the smaller light-sensitive area is illuminated and such that for far field the longitudinal coordinate of the object can be determined from time-of-flight measurement only. Thus, in the near field the longitudinal coordinate of the object can be determined from the first combined signal using the second sensor signals generated by the first and the second optical sensors; in the far field the longitudinal coordinate of the object can be determined from time-of-flight measurement only; and in an intermediate distance range both, the first longitudinal coordinate z1 determined from time-of-flight and the second longitudinal coordinate z2 determined from the first combined signal using the second sensor signals generated by the first and the second optical sensors may be obtained.

The evaluation device may be adapted to calibrate a determination of one of the first longitudinal coordinate z_1 or the second longitudinal coordinate z_2 by using the other one of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. The evaluation device may be adapted to calibrate a determination of the first longitudinal coordinate z_1 by using the second longitudinal coordinate z_2 and/or to calibrate a determination of the second longitudinal coordinate z_2 by using the first longitudinal coordinate z_1. As used herein, the term "calibration" refers to correcting and/or adjusting the determination of one of the first longitudinal coordinate z_1 or the second longitudinal coordinate z_2 in view of the other one of the first longitudinal coordinate z_1 or the second longitudinal coordinate z_2. The evaluation device may be adapted to determine a calibration function. For example, the evaluation device may be adapted to compare the first longitudinal coordinate and the second longitudinal coordinate. The evaluation device may be adapted to determine a difference of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. The evaluation device may be adapted to one or more of dividing, subtracting, multiplying the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. The evaluation device may be adapted to correct and/or adjust at least one of the first sensor signals; the second sensor signals; the first longitudinal coordinate; the second longitudinal coordinate; the first combined signal; the second combined signal by using the calibration function. This may allow further enhancing reliability of determination of the longitudinal coordinate.

The detector may be adapted to be run in at least two modes. In a first mode the detector may be adapted to determine the first longitudinal coordinate z_1. In a second mode the detector may be adapted to determine the second longitudinal coordinate z_2. The evaluation device may be adapted to select and/or adjust and/or choose one of the modes. For example, the detector may run in the first mode. The evaluation device may be adapted to determine the signal intensity of the first sensor signal. In case the signal intensity is determined to be high, the evaluation device may determine the first longitudinal coordinate without further running the detector in the second mode. The evaluation device may be adapted to determine a noise quantity of at least one of the following quantities: the first sensor signal, the second sensor signals, the first combined signal, the second combined signal, the first longitudinal coordinate, the second longitudinal coordinate. The noise quantity may for example be determined as the standard deviation with respect to a mean signal, a peak to peak signal, a signal variance, or the like. The first and second longitudinal coordinates may, in the same distance measurement, show different signal to noise ratios. Further, the first and second sensor signals may, in the same distance measurement, show different signal to noise ratios. Thus, in case the signal to noise ratio is lower for the first longitudinal coordinate, the evaluation device may be adapted to disregard the first longitudinal coordinate. In this case the evaluation device may be adapted to choose the second mode and to determine the second longitudinal coordinate therefrom and vice versa. This may allow enhancing accuracy of the determination of the longitudinal coordinate. Further, the evaluation device may be adapted to use one of the two longitudinal coordinates such as the first longitudinal coordinate, as long as the signal intensity of the first sensor signal is above a predefined value above which the determination of the first longitudinal coordinate is known and calibrated to be reliable, whereas the evaluation device is adapted to use the other longitudinal co-

ordinate such as the second longitudinal coordinate when the signal intensity of the first sensor signal falls below the predefined value.

The detector may be adapted to be run in a combined mode, wherein both the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2 are determined. At least one of the optical sensors may be adapted to generate at least one second combined signal, wherein the combined signal comprises the first sensor signal and at least one of the second sensor signals. The evaluation device may be adapted to compare the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. The evaluation device may be adapted to perform at least one plausibility check. The evaluation device may be adapted to determine a difference of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. The evaluation device may be adapted to determine if the difference is within at least one pre-determined and/or pre-defined limit. The evaluation device may be adapted to one or more of discarding the first longitudinal coordinate z_1 and/or the second longitudinal coordinate z_2 and outputting at least one warning, for example at least one warning message and/or at least one audible signal, if the difference is above the pre-determined and/or pre-defined limit. The plausibility check may be especially useful in highly reflective environments.

The evaluation device may be adapted to determine a combined longitudinal coordinate z_{comb} by evaluating both the first sensor signal and the second sensor signals and/or by evaluating both the first sensor signal and the first combined signal and/or by evaluating the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. For example, the evaluation device may be adapted to derive the combined longitudinal coordinate z_{comb} by determining an average value of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. For example, the evaluation device may be adapted to deriving the combined longitudinal coordinate z_{comb} by determining a longitudinal period by using the second sensor signals and by determining a position within the determined period by using the first sensor signal.

The detector may be adapted to determine at least one longitudinal coordinate over a larger measurement range or longitudinal range with lower precision, and at least one other longitudinal coordinate over a shorter measurement range or longitudinal range with a higher precision. For example, the detector may be adapted to determine the at least one longitudinal coordinate within a larger measurement range or longitudinal range such as from less than 0.1 m up to 10 m, with a precision of ±0.1 m, and to determine the other longitudinal coordinate within a measurement range of 0.2 m up to 8 m wherein the relative longitudinal coordinate may be determined within a longitudinal period of 1 m with a precision of ±0.05 m. The evaluation device may be adapted to use the second sensor signals and/or the second longitudinal coordinate to determine to which longitudinal period the first longitudinal coordinate corresponds and to further determine the absolute longitudinal coordinate.

The detector may be adapted to determine the at least one combined longitudinal coordinate with enhanced precision by using the second combined signal. In one embodiment, the first combined signal may have a precision ε_2 which may be lower than the precision of the first sen-

sor signal. The first sensor signal may be periodic within a first measurement range $z_{1,l}$ with a period length of $z_{1,p}$. Thus, the same first sensor signal may be obtained for the distance $z_{1,m}$ and a distance $z_{1,m}+nz_{1,p}$, where n is an integer and the distance $z_{1,m}+nz_{1,p}$ is within the first measurement range. A second measurement range of the first combined signal may be $z_{2,l}$ which may be identical to the first measurement range. The first combined signal may be unique within the whole measurement range. The precision of the determined longitudinal coordinate from the first combined signal may be lower than the precision of the determined longitudinal coordinate from the first sensor signal. However, the longitudinal coordinate obtained from the first combined signal may be unique, since the first combined signal may be a monotonous function of the distance within the whole measurement range. The evaluation device may be adapted to determine the combined longitudinal coordinate z_{comb} by

- determining non-unique first longitudinal coordinates $z_{1,m}$ from the first sensor signal;
- determining a unique longitudinal coordinate, $z_{2,m}$, from the first combined signal and
- determining the first longitudinal coordinate, z_1, which is within the interval $z_{2,m}\pm\varepsilon_2$.

The detector may be adapted to determine the at least one combined longitudinal coordinate with enhanced precision by considering a threshold intensity. The first sensor signal and the first combined signal may be monotonous functions of the longitudinal coordinate. The first combined signal may have a lower precision than the first sensor signal for smaller distances from the object to the detector and an even lower precision for higher distances from the object to the detector. The first sensor signal may have a high precision for all distances from the object to the detector if the second sensor signal intensity may be equal or higher than a predetermined threshold intensity of the second sensor signal $i_{2,a}$. However, the first sensor signal may have a reduced precision for low intensities of the second sensor signals and higher distances from the object to the detector. The evaluation device may be adapted to determine the combined longitudinal coordinate z_{comb} by determining the second sensor signal intensity i_2 and,

- if the second sensor signal intensity i_2 is equal or higher than the predetermined threshold intensity $i_{2,a}$, the combined longitudinal coordinate is determined to be the first longitudinal coordinate;
- if the second sensor signal intensity i_2 is lower than the predetermined threshold intensity $i_{2,a}$ and the second longitudinal coordinate is lower than a predetermined or selected distance threshold z_{limit}, the combined longitudinal coordinate is determined to be the first longitudinal coordinate;
- if the second sensor signal intensity is lower than the predetermined threshold intensity $i_{2,a}$ and the second longitudinal coordinate is higher than the distance threshold z_{limit}, the combined longitudinal coordinate is determined to be the second longitudinal coordinate.

The detector may be adapted to determine a plurality of combined longitudinal coordinates. If more than two second sensor signals are available, more than one combined first sensor signal may be formed. The detector may be adapted to determine the at least one combined longitudinal coordinate with enhanced precision by using the plurality of combined longitudinal coordinates. The first sensor signal and the second sensor signals may be monotonous functions of the longitudinal coordinate. The first combined signal may have a lower precision than the first

sensor signal for smaller distances from the object to the detector, and an even lower precision for higher distances from the object to the detector. The evaluation device may be adapted to determine a plurality of combined second sensor signals. For example, the evaluation device may be adapted to divide each of the second sensor signals, e.g. denoted as a, b, c and d, by one selected second sensor signal and to determine the combined second sensor signals, e.g. $s_{2,a/b}$, $s_{2,a/c}$, and $s_{2,d/c}$,. The first sensor signal may have a high precision for all distances from the object to the detector. However, the first sensor signal may have a reduced precision or may deliver wrong results in case of multi-path reflections, such as in environments where the illumination light beam may return directly and indirectly to the detector such as by reflections on metallic or other highly reflective surfaces. The evaluation device may be adapted to determine the combined longitudinal coordinate z_{comb} by

a) Determining the first longitudinal coordinate from the first sensor signal;
b) Determining the second longitudinal coordinate from one of the combined second sensor signals;
c) Determining a difference of the first and second longitudinal coordinates. If the difference is below a predetermined threshold value, the combined longitudinal coordinate is determined to be the first longitudinal coordinate. If the difference is equal or larger than a predetermined or selected threshold value, the combined longitudinal coordinate may be determined from the combined second sensor signals only. In particular a plurality of second longitudinal coordinates may be determined from each of the combined second sensor signals. The difference of the second longitudinal coordinates may be determined. If the difference between at least two of the second longitudinal coordinates is below a further predetermined or selected threshold value, the combined longitudinal coordinate is determined to be one of the two second longitudinal coordinates and/or an average of the two longitudinal coordinates. If the difference between at least two of the second longitudinal coordinates is equal or larger than the further predetermined or selected threshold value, an error signal is given, indicating a measurement with low confidence.

The combined longitudinal coordinate may be an average of all first and second longitudinal coordinates and/or the minimum or maximum of all first and second longitudinal coordinates, depending on the application.

The evaluation device may be adapted to determine at least one information about a signal quality, for example level of signal intensity, of the first sensor signal and the second sensor signals. The evaluation device may be adapted to select or discard dependent on the information about the signal quality at least one of the first sensor signal and/or the second sensor signals and to determine

- if the first sensor signal is selected, a longitudinal coordinate $z_{quality}$ of the object by evaluating the first sensor signal;
- if the second sensor signals are selected, the longitudinal coordinate $z_{quality}$ of the object by evaluating the first combined signal Q from the second sensor signals;
- if both the first sensor signal and the second sensor signals are selected, the longitudinal coordinate $z_{quality}$ of the object by evaluating both the first sensor signal and the second sensor signals and/or by evaluating both the first sensor signal and the first combined signal and/or by

evaluating the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2. The evaluation device may be adapted to determine whether the information about the signal quality is within at least one pre-defined limit.

In view of the technical challenges involved in the prior art documents discussed above, specifically in view of the technical effort which is required for generating the FiP effect, it has to be noted that the present invention specifically may be realized by using non-FiP optical sensors. In fact, since optical sensors having the FiP characteristic typically exhibit a strong peak in the respective sensor signals at a focal point, the range of measurement of a detector according to the present invention using FiP sensors as optical sensors may be limited to a range in between the two positions and which the optical sensors are in focus of the light beam. When using linear optical sensors, however, i.e. optical sensors not exhibiting the FiP effect, this problem, with the setup of the present invention, generally may be avoided. Consequently, the first and second optical sensor may each have, at least within a range of measurement, a linear signal characteristic such that the respective second sensor signals may be dependent on the total power of illumination of the respective optical sensor and may be independent from a diameter of a light spot of the illumination. It shall be noted, however, that other embodiments are feasible, too.

The optical sensors each specifically may be semiconductor sensors, preferably inorganic semiconductor sensors, more preferably photodiodes and most preferably silicon photodiodes. Thus, as opposed to complex and expensive FiP sensors, the present invention simply may be realized by using commercially available inorganic photodiodes, i.e. one small photodiode and one large area photodiode. Thus, the setup of the present invention may be realized in a cheap and inexpensive fashion.

Specifically, the optical sensors, each independently, may be or may comprise inorganic photodiodes which are sensitive in the infrared spectral range, preferably in the range of 780 nm to 3.0 micrometers, and/or sensitive in the visible spectral range, preferably in the range of 380 nm to 780 nm. Specifically, the optical sensors may be sensitive in the part of the near infrared region where silicon photodiodes are applicable specifically in the range of 700 nm to 1000 nm. Infrared optical sensors which may be used for the first optical sensor, for the second optical sensor or for both the first and second optical sensors may be commercially available infrared optical sensors, such as infrared optical sensors commercially available from Hamamatsu Photonics Deutschland GmbH, D-82211 Herrsching am Ammersee, Germany. Thus, as an example, the optical sensors may comprise at least one optical sensor of an intrinsic photovoltaic type, more preferably at least one semiconductor photodiode selected from the group consisting of: a Ge photodiode, an InGaAs photodiode, an extended InGaAs photodiode, an InAs photodiode, an InSb photodiode, a HgCdTe photodiode. Additionally or alternatively, the optical sensors may comprise at least one optical sensor of an extrinsic photovoltaic type, more preferably at least one semiconductor photodiode selected from the group consisting of: a Ge:Au photodiode, a Ge:Hg photodiode, a Ge:Cu photodiode, a Ge:Zn photodiode, a Si:Ga photodiode, a Si:As photodiode. Additionally or alternatively, the first optical sensor, the second optical sensor

or both the first and the second optical sensor may comprise at least one bolometer, preferably a bolometer selected from the group consisting of a VO bolometer and an amorphous Si bolometer.

The optical sensors each, independently, may be opaque, transparent or semitransparent. For the sake of simplicity, however, opaque sensors which are not transparent for the light beam, may be used, since these opaque sensors generally are widely commercially available.

The optical sensors each specifically may be uniform sensors having a single light-sensitive area each. Thus, the optical sensors specifically may be non-pixelated optical sensors.

The above-mentioned operations, including determining the at least one longitudinal coordinate of the object, are performed by the at least one evaluation device. Thus, as an example, one or more of the above-mentioned relationships may be implemented in software and/or hardware, such as by implementing one or more lookup tables. Thus, as an example, the evaluation device may comprise one or more programmable devices such as one or more computers, application-specific integrated circuits (ASICs), Field Programmable Gate Arrays (FPGAs), or digital signal processors (DSPs) which are configured to perform the above-mentioned evaluation, in order to determine the at least one longitudinal coordinate of the object. Additionally or alternatively, however, the evaluation device may also fully or partially be embodied by hardware.

As outlined above, by evaluating the first and second sensor signals, the detector may be enabled to determine the at least one longitudinal coordinate of the object, including the option of determining the longitudinal coordinate of the whole object or of one or more parts thereof. In addition, however, other coordinates of the object, including one or more transversal coordinates and/or rotational coordinates, may be determined by the detector, specifically by the evaluation device. Thus, as an example, one or more additional transversal sensors may be used for determining at least one transversal coordinate of the object. Various transversal sensors are generally known in the art, such as the transversal sensors disclosed in WO 2014/097181 A1 and/or other position-sensitive devices (PSDs), such as quadrant diodes, CCD or CMOS chips or the like. These devices may generally also be implemented into the detector according to the present invention. As an example, a part of the light beam may be split off within the detector, by at least one beam splitting element. The split-off portion, as an example, may be guided towards a transversal sensor, such as a CCD or CMOS chip or a camera sensor, and a transversal position of a light spot generated by the split-off portion on the transversal sensor may be determined, thereby determining at least one transversal coordinate of the object. Consequently, the detector according to the present invention may either be a one-dimensional detector, such as a simple distance measurement device, or may be embodied as a two-dimensional detector or even as a three-dimensional detector. Further, as outlined above or as outlined in further detail below, by scanning a scenery or an environment in a one-dimensional fashion, a three-dimensional image may also be created. Consequently, the detector according to the present invention specifically may be one of a one-dimensional detector, a two-

dimensional detector or a three-dimensional detector. The evaluation device may further be configured to determine at least one transversal coordinate x, y of the object.

As outlined above, the detector may further comprise one or more additional elements such as one or more additional optical elements. Further, the detector may fully or partially be integrated into at least one housing.

In an embodiment of the present invention, the detector may comprise at least one sensor element having a matrix of optical sensors, the optical sensors each having a light-sensitive area, wherein each optical sensor may be configured to generate the at least one second sensor signal in response to an illumination of the light-sensitive area by at least one light beam propagating from the object to the detector.

The at least one evaluation device may be configured for evaluating the second sensor signals, by

a) determining at least one optical sensor having the highest sensor signal and forming at least one center signal;
b) evaluating the sensor signals of the optical sensors of the matrix and forming at least one sum signal;
c) determining the at least one first combined signal by combining the center signal and the sum signal; and
d) determining the second longitudinal coordinate z_2 of the object by evaluating the first combined signal.

In this further preferred embodiment the optical sensors may be arranged such that the light-sensitive areas of the optical sensors differ in spatial offset and/or surface areas.

As further used herein, the term “matrix” generally refers to an arrangement of a plurality of elements in a predetermined geometrical order. The matrix, as will be outlined in further detail below, specifically may be or may comprise a rectangular matrix having one or more rows and one or more columns. The rows and columns specifically may be arranged in a rectangular fashion. It shall be outlined, however, that other arrangements are feasible, such as nonrectangular arrangements. As an example, circular arrangements are also feasible, wherein the elements are arranged in concentric circles or ellipses about a center point. For example, the matrix may be a single row of pixels. Other arrangements are feasible.

The optical sensors of the matrix specifically may be equal in one or more of size, sensitivity and other optical, electrical and mechanical properties. The light-sensitive areas of all optical sensors of the matrix specifically may be located in a common plane, the common plane preferably facing the object, such that a light beam propagating from the object to the detector may generate a light spot on the common plane.

As explained in more detail in one or more of the above-mentioned prior art documents, e.g. in WO 2012/110924 A1 or WO 2014/097181 A1, typically, a predetermined or determinable relationship exists between a size of a light spot, such as a diameter of the light spot, a beam waist or an equivalent diameter, and the longitudinal coordinate of the object from which the light beam propagates towards the detector. Without wishing to be bound by this theory, the light spot, may be characterized by two measurement variables: a measurement signal measured in a small measurement patch in the center or close to the center of the light spot, also referred to as the center signal, and an integral or sum signal integrated over the light spot, with or without the center signal. For a light beam having a certain total power which does not change when the beam is widened or focused, the sum signal should be independent from the spot size of the light spot, and, thus, should, at least when linear optical sensors within their respective measurement range are used, be independent from the distance between the object and the detector. The center signal, however, is dependent on the spot size. Thus, the center signal typically increases when the light beam is focused, and decreases when the light beam is defocused. By comparing the center signal and the sum signal, thus, an item of information on the size of the light spot generated by the light beam and, thus, on the longitudinal coordinate of the object may be generated. The comparing of the center signal and the sum signal, as an example, may be done by forming the first combined signal Q out of the center signal and the sum signal and by using a predetermined or determinable relationship between the second longitudinal coordinate and the first combined signal for deriving the second longitudinal coordinate.

The use of a matrix of optical sensors provides a plurality of advantages and benefits. Thus, the center of the light spot generated by the light beam on the sensor element, such as on the common plane of the light-sensitive areas of the optical sensors of the matrix of the sensor element, may vary with a transversal position of the object. By using a matrix of optical sensors, the detector according to the present invention may adapt to these changes in conditions and, thus, may determine the center of the light spot simply by comparing the sensor signals. Consequently, the detector according to the present invention may, by itself, choose the center signal and determine the sum signal and, from these two signals, derive a combined signal which contains information on the second longitudinal coordinate of the object. By evaluating the first combined signal, the second longitudinal coordinate of the object may, thus, be determined. The use of the matrix of optical sensors, thus, provides a significant flexibility in terms of the position of the object, specifically in terms of a transversal position of the object.
The transversal position of the light spot on the matrix of optical sensors, such as the transversal position of the at least one optical sensor generating the sensor signal, may even be used as an additional item of information, from which at least one item of information on a transversal position of the object may be derived, as e.g. disclosed in WO 2014/198629 A1. Additionally or alternatively, as will be outlined in further detail below, the detector according to the present invention may contain at least one additional transversal detector for, in addition to the at least one longitudinal coordinate, detecting at least one transversal coordinate of the object.

Consequently, in accordance with the present invention, the term “center signal” generally refers to the at least one sensor signal comprising essentially center information of the beam pro-

file. As used herein, the term "highest sensor signal" refers to one or both of a local maximum or a maximum in a region of interest. For example, the center signal may be the signal of the at least one optical sensor having the highest sensor signal out of the plurality of sensor signals generated by the optical sensors of the entire matrix or of a region of interest within the matrix, wherein the region of interest may be predetermined or determinable within an image generated by the optical sensors of the matrix. The center signal may arise from a single optical sensor or, as will be outlined in further detail below, from a group of optical sensors, wherein, in the latter case, as an example, the sensor signals of the group of optical sensors may be added up, integrated or averaged, in order to determine the center signal. The group of optical sensors from which the center signal arises may be a group of neighboring optical sensors, such as optical sensors having less than a predetermined distance from the actual optical sensor having the highest sensor signal, or may be a group of optical sensors generating sensor signals being within a predetermined range from the highest sensor signal. The group of optical sensors from which the center signal arises may be chosen as large as possible in order to allow maximum dynamic range. The evaluation device may be adapted to determine the center signal by integration of the plurality of sensor signals, for example the plurality of optical sensors around the optical sensor having the highest sensor signal. For example, the beam profile may be a trapezoid beam profile and the evaluation device may be adapted to determine an integral of the trapezoid, in particular of a plateau of the trapezoid.

Similarly, the term "sum signal" generally refers to a signal comprising essentially edge information of the beam profile. For example, the sum signal may be derived by adding up the sensor signals, integrating over the sensor signals or averaging over the sensor signals of the entire matrix or of a region of interest within the matrix, wherein the region of interest may be predetermined or determinable within an image generated by the optical sensors of the matrix. When adding up, integrating over or averaging over the sensor signals, the actual optical sensors from which the sensor signal is generated may be left out of the adding, integration or averaging or, alternatively, may be included into the adding, integration or averaging. The evaluation device may be adapted to determine the sum signal by integrating signals of the entire matrix, or of the region of interest within the matrix. For example, the beam profile may be a trapezoid beam profile and the evaluation device may be adapted to determine an integral of the entire trapezoid. Further, when trapezoid beam profiles may be assumed, the determination of edge and center signals may be replaced by equivalent evaluations making use of properties of the trapezoid beam profile such as determination of the slope and position of the edges and of the height of the central plateau and deriving edge and center signals by geometric considerations.

Additionally or alternatively, the evaluation device may be adapted to determine one or both of center information or edge information from at least one slice or cut of the light spot. This may be realized for example by replacing the area integrals in the first combined signal Q by a line integrals along the slice or cut. For improved accuracy, several slices or cuts through the light spot may be used and averaged. In case of an elliptical spot profile, averaging over several slices or cuts may result in an improved distance information.

The first combined signal may be a signal which is generated by combining the center signal and the sum signal. Specifically, the combination may include one or more of: forming a quotient of the center signal and the sum signal or vice versa; forming a quotient of a multiple of the center signal and a multiple of the sum signal or vice versa; forming a quotient of a linear combination of the center signal and a linear combination of the sum signal or vice versa. Additionally or alternatively, the combined signal may comprise an arbitrary signal or signal combination which contains at least one item of information on a comparison between the center signal and the sum signal.

The light beam propagating from the object to the detector specifically may fully illuminate the at least one optical sensor from which the center signal is generated, such that the at least one optical sensor from which the center signal arises is fully located within the light beam, with a width of the light beam being larger than the light-sensitive area of the at least one optical sensor from which the sensor signal arises. Contrarily, preferably, the light beam propagating from the object to the detector specifically may create a light spot on the entire matrix which is smaller than the matrix, such that the light spot is fully located within the matrix. This situation may easily be adjusted by a person skilled in the art of optics by choosing one or more appropriate lenses or elements having a focusing or defocusing effect on the light beam, such as by using an appropriate transfer device as will be outlined in further detail below. As further used herein, a “light spot” generally refers to a visible or detectable round or non-round illumination of an article, an area or object by a light beam.

Specifically, as will be outlined in further detail below, the evaluation device may be configured to determine the at least one second longitudinal coordinate z_2 of the object by using at least one known, determinable or predetermined relationship between the sensor signals. In particular, the evaluation device is configured to determine the at least one coordinate z of the object by using at least one known, determinable or predetermined relationship between a first combined signal derived from the sensor signals and the second longitudinal coordinate.

As outlined above, the center signal generally may be a single sensor signal, such as a sensor signal from the optical sensor in the center of the light spot, or may be a combination of a plurality of sensor signals, such as a combination of sensor signals arising from optical sensors in the center of the light spot, or a secondary sensor signal derived by processing a sensor signal derived by one or more of the aforementioned possibilities. The determination of the center signal may be performed electronically, since a comparison of sensor signals is fairly simply implemented by conventional electronics, or may be performed fully or partially by software. Specifically, the center signal may be selected from the group consisting of: the highest sensor signal; an average of a group of sensor signals being within a predetermined range of tolerance from the highest sensor signal; an average of sensor signals from a group of optical sensors containing the optical sensor having the highest sensor signal and a predetermined group of neighboring optical sensors; a sum of sensor signals from a group of optical sensors containing the optical sensor having the highest sensor signal and a predetermined group of neighboring optical

sensors; a sum of a group of sensor signals being within a predetermined range of tolerance from the highest sensor signal; an average of a group of sensor signals being above a predetermined threshold; a sum of a group of sensor signals being above a predetermined threshold; an integral of sensor signals from a group of optical sensors containing the optical sensor having the highest sensor signal and a predetermined group of neighboring optical sensors; an integral of a group of sensor signals being within a predetermined range of tolerance from the highest sensor signal; an integral of a group of sensor signals being above a predetermined threshold.

As outlined above, raw sensor signals of the optical sensors may be used for evaluation or secondary sensor signals derived thereof. As used herein, the term “secondary sensor signal” generally refers to a signal, such as an electronic signal, more preferably an analogue and/or a digital signal, which is obtained by processing one or more raw signals, such as by filtering, averaging, demodulating or the like. Thus, image processing algorithms may be used for generating secondary sensor signals from the totality of sensor signals of the matrix or from a region of interest within the matrix. Specifically, the detector, such as the evaluation device, may be configured for transforming the sensor signals of the optical sensor, thereby generating secondary optical sensor signals, wherein the evaluation device is configured for performing steps a)-d) by using the secondary optical sensor signals. The transformation of the sensor signals specifically may comprise at least one transformation selected from the group consisting of: a filtering; a selection of at least one region of interest; a formation of a difference image between an image created by the sensor signals and at least one offset; an inversion of sensor signals by inverting an image created by the sensor signals; a formation of a difference image between an image created by the sensor signals at different times; a background correction; a decomposition into color channels; a decomposition into hue; saturation; and brightness channels; a frequency decomposition.; a singular value decomposition; applying a Canny edge detector; applying a Laplacian of Gaussian filter; applying a Difference of Gaussian filter; applying a Sobel operator; applying a Laplace operator; applying a Scharr operator; applying a Prewitt operator; applying a Roberts operator; applying a Kirsch operator; applying a high-pass filter; applying a low-pass filter; applying a Fourier transformation; applying a Radon-transformation; applying a Hough-transformation; applying a wavelet-transformation; a thresholding; creating a binary image. The region of interest may be determined manually by a user or maybe determined automatically, such as by recognizing an object within an image generated by the optical sensors. As an example, a vehicle, a person or another type of predetermined object may be determined by automatic image recognition within an image, i.e. within the totality of sensor signals generated by the optical sensors, and the region of interest may be chosen such that the object is located within the region of interest. In this case, the evaluation, such as the determination of the second longitudinal coordinate, may be performed for the region of interest, only. Other implementations, however, are feasible.

As outlined above, the detection of the center of the light spot, i.e. the detection of the center signal and/or of the at least one optical sensor from which the center signal arises, may be performed fully or partially electronically or fully or partially by using one or more software algo-

rithms. Specifically, the evaluation device may comprise at least one center detector for detecting the at least one highest sensor signal and/or for forming the center signal. The center detector specifically may fully or partially be embodied in software and/or may fully or partially be embodied in hardware. The center detector may fully or partially be integrated into the at least one sensor element and/or may fully or partially be embodied independently from the sensor element.

As outlined above, the sum signal may be derived from all sensor signals of the matrix, from the sensor signals within a region of interest or from one of these possibilities with the sensor signals arising from the optical sensors contributing to the center signal excluded. In every case, a reliable sum signal may be generated which may be compared with the center signal reliably, in order to determine the second longitudinal coordinate. Generally, the sum signal may be selected from the group consisting of: an average over all sensor signals of the matrix; a sum of all sensor signals of the matrix; an integral of all sensor signals of the matrix; an average over all sensor signals of the matrix except for sensor signals from those optical sensors contributing to the center signal; a sum of all sensor signals of the matrix except for sensor signals from those optical sensors contributing to the center signal; an integral of all sensor signals of the matrix except for sensor signals from those optical sensors contributing to the center signal; a sum of sensor signals of optical sensors within a predetermined range from the optical sensor having the highest sensor signal; an integral of sensor signals of optical sensors within a predetermined range from the optical sensor having the highest sensor signal; a sum of sensor signals above a certain threshold of optical sensors being located within a predetermined range from the optical sensor having the highest sensor signal; an integral of sensor signals above a certain threshold of optical sensors being located within a predetermined range from the optical sensor having the highest sensor signal. Other options, however, exist.

The summing may be performed fully or partially in software and/or may be performed fully or partially in hardware. A summing is generally possible by purely electronic means which, typically, may easily be implemented into the detector. Thus, in the art of electronics, summing devices are generally known for summing two or more electrical signals, both analogue signals and digital signals. Thus, the evaluation device may comprise at least one summing device for forming the sum signal. The summing device may fully or partially be integrated into the sensor element or may fully or partially be embodied independently from the sensor element. The summing device may fully or partially be embodied in one or both of hardware or software.

As outlined above, the comparison between the center signal and the sum signal specifically may be performed by forming one or more quotient signals. Thus, generally, the first combined signal may be a quotient signal Q, derived by one or more of: forming a quotient of the center signal and the sum signal or vice versa; forming a quotient of a multiple of the center signal and a multiple of the sum signal or vice versa; forming a quotient of a linear combination of the center signal and a linear combination of the sum signal or vice versa; forming a quotient of the center signal and a linear combination of the sum signal and the center signal or vice versa; forming a quotient of the sum signal and a linear combination of the sum signal and the center

signal or vice versa; forming a quotient of an exponentiation of the center signal and an exponentiation of the sum signal or vice versa. Other options, however, exist. The evaluation device may be configured for forming the one or more quotient signals. The evaluation device may further be configured for determining the at least one longitudinal coordinate by evaluating the at least one quotient signal.

The evaluation device specifically may be configured for using at least one predetermined relationship between the first combined signal Q and the second longitudinal coordinate, in order to determine the at least one longitudinal coordinate. Thus, due to the reasons disclosed above and due to the dependency of the properties of the light spot on the second longitudinal coordinate, the first combined signal Q typically is a monotonous function of the second longitudinal coordinate of the object and/or of the size of the light spot such as the diameter or equivalent diameter of the light spot. Thus, as an example, specifically in case linear optical sensors are used, a simple quotient of the sensor signal s_{center} and the sum signal s_{sum} $Q=s_{center}/s_{sum}$ may be a monotonously decreasing function of the distance. Without wishing to be bound by this theory, it is believed that this is due to the fact that, in the preferred setup described above, both the center signal s_{center} and the sum signal s_{sum} decrease as a square function with increasing distance to the light source, since the amount of light reaching the detector decreases. Therein, however, the center signal s_{center} decreases more rapidly than the sum signal s_{sum}, since, in the optical setup as used in the experiments, the light spot in the image plane grows and, thus, is spread over a larger area. The quotient of the center signal and the sum signal, thus, continuously decreases with increasing diameter of the light beam or diameter of the light spot on the light-sensitive areas of the optical sensors of the matrix. The quotient, further, is typically independent from the total power of the light beam, since the total power of the light beam forms a factor both in the center signal and in the sum sensor signal. Consequently, the quotient Q may form a secondary signal which provides a unique and unambiguous relationship between the center signal and the sum signal and the size or diameter of the light beam. Since, on the other hand, the size or diameter of the light beam is dependent on a distance between the object, from which the light beam propagates towards the detector, and the detector itself, i.e. dependent on the longitudinal coordinate of the object, a unique and unambiguous relationship between the center signal and the sum signal on the one hand and the longitudinal coordinate on the other hand may exist. For the latter, reference e.g. may be made to one or more of the above-mentioned prior art documents, such as WO 2014/097181 A1. The predetermined relationship may be determined by analytical considerations, such as by assuming a linear combination of Gaussian light beams, by empirical measurements, such as measurements measuring the combined signal and/or the center signal and the sum signal or secondary signals derived thereof as a function of the longitudinal coordinate of the object, or both.

Thus, generally, the evaluation device may be configured for determining the second longitudinal coordinate by evaluating the quotient signal Q such as the combined signal. This determining may be a one-step process, such as by directly combining the center signal and the sum signal and deriving the second longitudinal coordinate thereof, or may be a multiple step process, such as by firstly deriving the combined signal from the center signal and the sum signal

and, secondly, by deriving the second longitudinal coordinate from the combined signal. Both options, i.e. the option of steps c) and d) being separate and independent steps and the option of steps c) and d) being fully or partially combined, shall be comprised by the present invention.

The evaluation device may be configured for using at least one predetermined relationship between the combined signal and the second longitudinal coordinate. The predetermined relationship may be one or more of an empiric relationship, a semi-empiric relationship and an analytically de-rived relationship. The evaluation device may comprise at least one data storage device for storing the predetermined relationship, such as a lookup list or a lookup table.

The quotient signal Q may be determined by using various means. As an example, a software means for deriving the quotient signal, a hardware means for deriving the quotient signal, or both, may be used and may be implemented in the evaluation device. Thus, the evaluation device, as an example, may comprise at least one divider, wherein the divider is configured for deriving the quotient signal. The divider may fully or partially be embodied as one or both of a software divider or a hardware divider. The divider may fully or partially be integrated into the sensor element answers or may fully or partially be embodied independent from the sensor element.

As outlined above, the optical sensors specifically may be or may comprise photodetectors, preferably inorganic photodetectors, more preferably inorganic semiconductor photodetectors, most preferably silicon photodetectors. Specifically, the optical sensors may be sensitive in the infrared spectral range. All of the optical sensors of the matrix or at least a group of the optical sensors of the matrix specifically may be identical. Groups of identical optical sensors of the matrix specifically may be provided for different spectral ranges, or all optical sensors may be identical in terms of spectral sensitivity. Further, the optical sensors may be identical in size and/or with regard to their electronic or optoelectronic properties.

Specifically, the optical sensors may be or may comprise inorganic photodiodes which are sensitive in the infrared spectral range, preferably in the range of 780 nm to 3.0 micrometers. Specifically, the optical sensors may be sensitive in the part of the near infrared region where silicon photodiodes are applicable specifically in the range of 700 nm to 1000 nm. Infrared optical sensors which may be used for optical sensors may be commercially available infrared optical sensors, such as infrared optical sensors commercially available from Hamamatsu Photonics Deutschland GmbH, D-82211 Herrsching am Ammersee, Germany. Thus, as an example, the optical sensors may comprise at least one optical sensor of an intrinsic photovoltaic type, more preferably at least one semiconductor photodiode selected from the group consisting of: a Ge photodiode, an InGaAs photodiode, an extended InGaAs photodiode, an InAs photodiode, an InSb photodiode, a HgCdTe photodiode. Additionally or alternatively, the optical sensors may comprise at least one optical sensor of an extrinsic photovoltaic type, more preferably at least one semiconductor photodiode selected from the group consisting of: a Ge:Au photodiode, a Ge:Hg photodiode, a Ge:Cu photodiode, a Ge:Zn photodiode, a Si:Ga photodiode, a Si:As photodiode. Additionally or alternatively, the optical sensors may comprise at least one bolometer,

preferably a bolometer selected from the group consisting of a VO bolometer and an amorphous Si bolometer.

The matrix may be composed of independent optical sensors. Thus, a matrix of inorganic photodiodes may be composed. Alternatively, however, a commercially available matrix may be used, such as one or more of a CCD detector, such as a CCD detector chip, and/or a CMOS detector, such as a CMOS detector chip.

Thus, generally, the optical sensors of the detector may form a sensor array or may be part of a sensor array, such as the above-mentioned matrix. Thus, as an example, the detector may comprise an array of optical sensors, such as a rectangular array, having m rows and n columns, with m, n, independently, being positive integers. Preferably, more than one column and more than one row is given, i.e. n>1, m>1. Thus, as an example, n may be 2 to 16 or higher and m may be 2 to 16 or higher. Preferably, the ratio of the number of rows and the number of columns is close to 1. As an example, n and m may be selected such that $0.3 \leq m/n \leq 3$, such as by choosing m/n = 1:1, 4:3, 16:9 or similar. As an example, the array may be a square array, having an equal number of rows and columns, such as by choosing m=2, n=2 or m=3, n=3 or the like.

As further outlined above, the matrix specifically may be a rectangular matrix having at least one row, preferably a plurality of rows, and a plurality of columns. As an example, the rows and columns may be oriented essentially perpendicular, wherein, with respect to the term " essentially perpendicular", reference may be made to the definition given above. Thus, as an example, tolerances of less than 20°, specifically less than 10° or even less than 5°, may be acceptable. In order to provide a wide range of view, the matrix specifically may have at least 10 rows, preferably at least 50 rows, more preferably at least 100 rows. Similarly, the matrix may have at least 10 columns, preferably at least 50 columns, more preferably at least 100 columns. The matrix may comprise at least 50 optical sensors, preferably at least 100 optical sensors, more preferably at least 500 optical sensors. The matrix may comprise a number of pixels in a multi-mega pixel range. Other embodiments, however, are feasible. Thus, as outlined above, in setups in which an axial rotational symmetry is to be expected, circular arrangements or concentric arrangements of the optical sensors of the matrix, which may also be referred to as pixels, may be preferred.

As further outlined above, preferably, the sensor element may be oriented essentially perpendicular to an optical axis of the detector. Again, with respect to the term "essentially perpendicular", reference may be made to the definition and the tolerances given above. The optical axis may be a straight optical axis or may be bent or even split, such as by using one or more deflection elements and/or by using one or more beam splitters, wherein the essentially perpendicular orientation, in the latter cases, may refer to the local optical axis in the respective branch or beam path of the optical setup.

In view of the technical challenges involved in the prior art documents discussed above, specifically in view of the technical effort which is required for generating the FiP effect, it has to be noted that the present invention specifically may be realized by using non-FiP optical sensors. In fact, since optical sensors having the FiP characteristic typically exhibit a strong peak in the respective sensor signals at a focal point, the range of measurement of a detector according to the present invention using FiP sensors as optical sensors may be limited to a range in between the positions and which the optical sensors are in focus of the light beam. When using linear optical sensors, however, i.e. optical sensors not exhibiting the FiP effect, this problem, with the setup of the present invention, generally may be avoided. Consequently, the optical sensors each may have, at least within a range of measurement, a linear signal characteristic such that the respective sensor signals are dependent on the total power of illumination of the respective optical sensor.

The detector may further comprise an illumination source for illuminating the object. As an example, the illumination source may be configured for generating an illuminating light beam for illuminating the object. The detector may be configured such that the illuminating light beam propagates from the detector towards the object along an optical axis of the detector. For this purpose, the detector may comprise at least one reflective element, preferably at least one prism, for deflecting the illuminating light beam onto the optical axis.

As outlined above, the illumination source, specifically, may be configured for emitting light in the infrared spectral range. It shall be noted, however, that other spectral ranges are feasible, additionally or alternatively. Further, the illumination source, as outlined above, specifically may be configured for emitting modulated or non-modulated light. In case a plurality of illumination sources is used, the different illumination sources may have different modulation frequencies which, as outlined in further detail below, later on may be used for distinguishing the light beams. The illumination source may be adapted to generate and/or to project a cloud of points, for example the illumination source may comprise one or more of at least one digital light processing (DLP) projector, at least one LCoS projector, at least one spatial light modulator; at least one diffractive optical element; at least one array of light emitting diodes; at least one array of laser light sources.

The above-mentioned operations, including determining the at least one longitudinal coordinate of the object, are performed by the at least one evaluation device. Thus, as an example, one or more of the above-mentioned relationships may be implemented in software and/or hardware, such as by implementing one or more lookup tables. Thus, as an example, the evaluation device may comprise one or more programmable devices such as one or more computers, application-specific integrated circuits (ASICs), Digital Signal Processors (DSPs), or Field Programmable Gate Arrays (FPGAs) which are configured to perform the above-mentioned evaluation, in order to determine the at least one longitudinal coordinate of the object. Additionally or alternatively, however, the evaluation device may also fully or partially be embodied by hardware.

As outlined above, by evaluating the center signal and the sum signal, the detector may be enabled to determine the at least one longitudinal coordinate of the object, including the option of determining the second longitudinal coordinate of the whole object or of one or more parts thereof. In addition, however, other coordinates of the object, including one or more transversal coordinates and/or rotational coordinates, may be determined by the detector, specifically by the evaluation device. Thus, as an example, one or more transversal sensors may be used for determining at least one transversal coordinate of the object. As outlined above, the position of the at least one optical sensor from which the center signal arises may provide information on the at least one transversal coordinate of the object, wherein, as an example, a simple lens equation may be used for optical transformation and for deriving the transversal coordinate. Additionally or alternatively, one or more additional transversal sensors may be used and may be comprised by the detector. Various transversal sensors are generally known in the art, such as the transversal sensors disclosed in WO 2014/097181 A1 and/or other position-sensitive devices (PSDs), such as quadrant diodes, CCD or CMOS chips or the like. Additionally or alternatively, as an example, the detector according to the present invention may comprise one or more PSDs disclosed in R.A. Street (Ed.): *Technology and Applications of Amorphous Silicon*, Springer-Verlag Heidelberg, 2010, pp. 346-349. Other embodiments are feasible. These devices may generally also be implemented into the detector according to the present invention. As an example, a part of the light beam may be split off within the detector, by at least one beam splitting element. The split-off portion, as an example, may be guided towards a transversal sensor, such as a CCD or CMOS chip or a camera sensor, and a transversal position of a light spot generated by the split-off portion on the transversal sensor may be determined, thereby determining at least one transversal coordinate of the object. Consequently, the detector according to the present invention may either be a one-dimensional detector, such as a simple distance measurement device, or may be embodied as a two-dimensional detector or even as a three-dimensional detector. Further, as outlined above or as outlined in further detail below, by scanning a scenery or an environment in a one-dimensional fashion, a three-dimensional image may also be created. Consequently, the detector according to the present invention specifically may be one of a one-dimensional detector, a two-dimensional detector or a three-dimensional detector. The evaluation device may further be configured to determine at least one transversal coordinate x, y of the object. The evaluation device may be adapted to combine the information of the longitudinal coordinate and the transversal coordinate and to determine a position of the object in space.

The detector may be configured for evaluating a single light beam or a plurality of light beams. In case a plurality of light beams propagates from the object to the detector, means for distinguishing the light beams may be provided. Thus, the light beams may have different spectral properties, and the detector may comprise one or more wavelength selective elements for distinguishing the different light beams. Each of the light beams may then be evaluated independently. The wavelength selective elements, as an example, may be or may comprise one or more filters, one or more prisms, one or more gratings, one or more dichroitic mirrors or arbitrary combinations thereof. Further, additionally or alternatively, for distinguishing two or more light beams, the light beams may be modulated in a specific fashion. Thus, as an example, the light beams may be frequency modulated, and the sensor signals may be demodulated in order

to distinguish partially the sensor signals originating from the different light beams, in accordance with their demodulation frequencies. These techniques generally are known to the skilled person in the field of high-frequency electronics. Generally, the evaluation device may be configured for distinguishing different light beams having different modulations.

The illumination source may be adapted to generate and/or to project a cloud of points such that a plurality of illuminated regions is generated on the matrix of optical sensor, for example the CMOS detector. Additionally, disturbances may be present on the matrix of optical sensor such as disturbances due to speckles and/or extraneous light and/or multiple reflections. The evaluation device may be adapted to determine at least one region of interest, for example one or more pixels illuminated by the light beam which are used for determination of the longitudinal coordinate of the object. For example, the evaluation device may be adapted to perform a filtering method, for example, a blob-analysis and/or object recognition method.

As outlined above, the detector may further comprise one or more additional elements such as one or more additional optical elements. Further, the detector may fully or partially be integrated into at least one housing.

In a further embodiment the detector may comprise at least two optical sensors, each optical sensor having a light-sensitive area, wherein each light-sensitive area has a geometrical center, wherein the geometrical centers of the optical sensors are spaced apart from an optical axis of the detector by different spatial offsets, wherein each optical sensor is configured to generate the at least one second sensor signal in response to an illumination of its respective light-sensitive area by a light beam propagating from the object to the detector.

The at least one evaluation device may be configured for determining the at least one second longitudinal coordinate z_2 of the object by combining the at least two second sensor signals.

The optical sensors may be arranged such that the light-sensitive areas of the optical sensors differ in their spatial offset and/or their surface areas

The light-sensitive areas of the optical sensors may overlap, as visible from the object, or may not overlap, i.e. may be placed next to each other without overlap. The light-sensitive areas may be spaced apart from each other or may directly be adjacent.

The detector may have an optical axis. The optical axis generally may denote the beam path. Therein, the detector may have a single beam path along which a light beam may travel from the object to the optical sensors, or may have a plurality of beam paths. As an example, a single beam path may be given or the beam path may be split into two or more partial beam paths. In the latter case, each partial beam path may have its own optical axis, and the condition noted above generally may refer to each beam path independently. The optical sensors may be located in one and the same beam path or partial beam path. Alternatively, however, the optical sensors may also be located in different partial beam paths. In case the optical sensors are distrib-

uted over different partial beam paths, the above-mentioned condition may be described such that at least one first optical sensor is located in at least one first partial beam path, being offset from the optical axis of the first partial beam path by a first spatial offset, and at least one second optical sensor is located in at least one second partial beam path, being offset from the optical axis of the second partial beam path by at least one second spatial offset, wherein the first spatial offset and the second spatial offset are different.

The detector may comprise more than two optical sensors. In any case, i.e. in the case of the detector comprising precisely two optical sensors and in the case of the detector comprising more than two optical sensors, the optical sensors may comprise at least one first optical sensor being spaced apart from the optical axis by a first spatial offset and at least one second optical sensor being spaced apart from the optical axis by a second spatial offset, wherein the first spatial offset and the second spatial offset differ. In case further optical sensors are provided, besides the first and second optical sensors, these additional optical sensors may also fulfill the condition or, alternatively, may be spaced apart from the optical axis by the first spatial offset, by the second spatial offset or by a different spatial offset. The first and second spatial offsets, as an example, may differ by at least a factor of 1.2, more preferably by at least a factor of 1.5, more preferably by at least a factor of two. The spatial offsets may also be zero or may assume negative values, as long as the above-mentioned conditions are fulfilled.

As outlined above, each light-sensitive area has a geometrical center. Each geometrical center of each light-sensitive area may be spaced apart from the optical axis of the detector, such as the optical axis of the beam path or the respective beam path in which the respective optical sensor is located.

As outlined above, the optical sensors specifically may be located in one and the same plane, which, preferably, is a plane perpendicular to the optical axis. Other configurations, however, are possible. Thus, two or more of the optical sensors may also be spaced apart in a direction parallel to the optical axis.

For example, the optical sensors may be partial diodes of a segmented diode, with a center of the segmented diode being off-centered from the optical axis of the detector. As used herein, the term “partial diode” may comprise several diodes that are connected in series or in parallel. This example is rather simple and cost-efficiently realizable. Thus, as an example, bi-cell diodes or quadrant diodes are widely commercially available at low cost, and driving schemes for these bi-cell diodes or quadrant diodes are generally known. As used herein, the term “bi-cell diode” generally refers to a diode having two partial diodes in one packaging. Bi-cell and quadrant diodes may have two or four separate light sensitive areas, in particular two or four active areas. As an example, the bi-cell diodes may each form independent diodes having the full functionality of a diode. As an example, each of the bi-cell diodes may have a square or rectangular shape, and the two diodes may be placed in one plane such that the two partial diodes, in total, form a 1 x 2 or 2 x 1 matrix having a rectangular shape. In the present invention, however, a new scheme for evaluating the sensor signals of the bi-cell diodes and quadrant diode is pro-

posed, as will be outlined in further detail below. Generally, however, the optical sensors specifically may be partial diodes of a quadrant diode, with a center of the quadrant diode being off-centered from the optical axis of the detector. As used herein, the term "quadrant diode" generally refers to a diode having four partial diodes in one packaging. As an example, the four partial diodes may each form independent diodes having the full functionality of a diode. As an example, the four partial diodes may each have a square or rectangular shape, and the four partial diodes may be placed in one plane such that the four partial diodes, in total, form a 2 x 2 matrix having a rectangular or square shape. In a further example, the four partial diodes, in total, may form a 2 x 2 matrix having a circular or elliptical shape. The partial diodes, as an example, may be adjacent, with a minimum separation from one another.

In case a quadrant diode is used, having a 2×2 matrix of partial diodes, the center of the quadrant diode specifically may be off-centered or offset from the optical axis. Thus, as an example, the center of the quadrant diodes, which may be an intersection of the geometrical centers of the optical sensors of the quadrant diode, may be off-centered from the optical axis by at least 0.2 mm, more preferably by at least 0.5 mm, more preferably by at least 1.0 mm or even 2.0 mm. Similarly, when using other types of optical sensors setups having a plurality of optical sensors, an overall center of the optical sensors may be offset from the optical axis by the same distance.

Generally, the light-sensitive areas of the optical sensors may have an arbitrary surface area or size. Preferably, however, specifically in view of a simplified evaluation of the sensor signals, the light-sensitive areas of the optical sensors are substantially equal, such as within a tolerance of less than 10%, preferably less than 5% or even less than 1%. This, specifically, is the case in typical commercially available quadrant diodes.

For detectors used in safety applications or applications requiring a certain level of functional safety or for detectors designed as such that a certain safety integrity level may be achieved, the detector may be designed as such that the first and second sensor signals are evaluated using separate partial diodes and/or separate electronic circuits and/or separate evaluation devices in order to ensure a high defect diagnostics and/or a low failure rate and/or a high mean time to failure.

Specifically, the evaluation device may be configured to determine the at least one second longitudinal coordinate z_2 of the object by using at least one known, determinable or predetermined relationship between second sensor signals and/or any secondary signal derived thereof and the longitudinal coordinate. Thus, the evaluation device may be configured for determining at least one combined signal out of the at least two second sensor signals, i.e. of the at least one second sensor signal of at least one first optical sensor and out of the at least one second sensor signal of at least one second optical sensor.

As generally used herein, the term "combine" generally may refer to an arbitrary operation in which two or more components such as signals are one or more of mathematically merged in

order to form at least one merged combined signal and/or compared in order to form at least one comparison signal or comparison result. As will be outlined in further detail below, the combined signal or secondary signal may be or may comprise at least one quotient signal.

Specifically, as will be outlined in further detail below, the evaluation device may be configured to determine the at least one second longitudinal coordinate z_2 of the object by using at least one known, determinable or predetermined relationship between the second sensor signals. In particular, the evaluation device is configured to determine the at least one coordinate z of the by using at least one known, determinable or predetermined relationship between the quotient signal derived from the second sensor signals and the second longitudinal coordinate. In case more than two second sensor signals are provided, as an example, more than one first combined signal may be generated, such as by forming quotient signals of more than one pair of second sensor signals.

As an example, Q may simply be determined as

$$Q = s_1/s_2$$

or

$$Q = s_2/s_1,$$

with s_1 denoting a first one of the second sensor signals and s_2 denoting a second one of the second sensor signals. Additionally or alternatively, Q may be determined as

$$Q = j \cdot s_1/k \cdot s_2$$

or

$$Q = k \cdot s_2/ j \cdot s_1,$$

with j and k being real numbers which, as an example, may be predetermined or determinable. Additionally or alternatively, Q may be determined as

$$Q = (j \cdot s_1 + k \cdot s_2) / (p \cdot s_1 + q \cdot s_2),$$

with j, k, p and q being real numbers which, as an example, may be predetermined or determinable. As a simple example for the latter, Q may be determined as

$$Q = s_1 / (s_1 + s_2),$$

or, as a further example, Q may be determined as

$$Q = (s_1 - s_2) / (s_1 + s_2).$$

Other quotient signals are feasible. Thus, as an example, in case more than two optical sensors are provided, the above-mentioned quotient formation may take place between two of the second sensor signals generated by these optical sensors or may take place between more than two of the second sensor signals. Thus, instead of using the first one of the second sensor signals and the second one of the second sensor signals in the formulae given above, combined signals may be used for quotient formation.

Without wishing to be bound by theory, the first combined signal Q generally is an example for an asymmetry or inhomogeneity parameter denoting an asymmetry or inhomogeneity or an asymmetric or homogeneous distribution of the light spot generated by the light beam on the light-sensitive areas. The quotient of the two or more optical sensors, such as the two or more photodiodes, may provide a combined signal which typically is monotonously dependent on the distance between the detector and the object from which the light beam travels towards the detector, as will be shown by experimental data below. In addition or as an alternative to the quotient signal, other types of combined functions implementing the sensor signals of two or more sensors in the setup of the present invention may be used, which also may show a dependency on the distance between the object and the detector. The asymmetry or inhomogeneity or the asymmetry or inhomogeneity parameter of the light spot, as an example, may be an indication of the width of a light beam. If this asymmetry parameter depends on the distance only, the measurement can be used to determine the distance.

In typical setups, commercially available quadrant diodes such as quadrant photodiodes are used for positioning, i.e. for adjusting and/or measuring a transversal coordinate of a light spot in the plane of the quadrant photodiode. Thus, as an example, laser beam positioning by using quadrant photodiodes is well known. According to a typical prejudice, however, quadrant photodiodes are used for xy-positioning, only. According to this assumption, quadrant photodiodes are not suitable for measuring distances. The above-mentioned findings, however, using an off-centered quadrant photodiode with regard to an optical axis of the detector, show otherwise, as will be shown in further measurements below. Thus, as indicated above, in quadrant photodiodes, the asymmetry of the spot can be measured by shifting the quadrant diode slightly off-axis, such as by the above-mentioned offset. Thereby, a monotonously z-dependent function may be generated, such as by forming the quotient signal Q of two or more of the sensor signals of two or more partial photodiodes, i.e. quadrants, of the quadrant photodiode. Therein, in principle, only two photodiodes are necessary for the measurement. The other two diodes may be used for noise cancellation or to obtain a more precise measurement.

In addition or as an alternative to using a quadrant diode or quadrant photodiode, other types of optical sensors may be used. Thus, as will be shown in further detail below, staggered optical sensors may be used.

The use of quadrant diodes provides a large number of advantages over known optical detectors. Thus, quadrant diodes are used in a large number of applications in combination with

LEDs or active targets and are widely commercially available at very low price, with various optical properties such as spectral sensitivities and in various sizes. No specific manufacturing process has to be established, since commercially available products may be implemented into the detector according to the present invention.

The detector according to the present invention specifically may be used in multilayer optical storage discs, such as disclosed by international patent application number PCT/IB2015/052233, filed on March 26, 2015. Measurements performed by using the detector according to the present invention specifically may be used in order to optimize the focus position in optical storage discs.

As will be outlined in further detail below, the distance measurement by using the detector according to the present invention may be enhanced by implementing one or more additional distance measurement means into the detector and/or by combining the detector with other types of distance measurement means. Thus, as an example, the detector may comprise or may be combined with at least one triangulation distance measurement device. Thus, the distance measurement can be enhanced by making use of a combination of the measurement principle discussed above and a triangulation type distance measurement. Further, means for measuring one or more other coordinates, such as x- and/or y-coordinates, may be provided.

In case a quadrant diode is used, the quadrant diode may also be used for additional purposes. Thus, the quadrant diode may also be used for conventional x-y-measurements of a light spot, as generally known in the art of optoelectronics and laser physics. Thus, as an example, the lens or detector position can be adjusted using the conventional xy-position information of the quadrant diode to optimize the position of the spot for the distance measurement. As a practical example, the light spot, initially, may be located right in the center of the quadrant diode, which typically does not allow for the above-mentioned distance measurement using the quotient function Q. Thus, firstly, conventional quadrant photodiode techniques may be used for off-centering a position of the light spot on the quadrant photodiode, such that, e.g., the spot position on the quadrant diode is optimal for the measurement. Thus, as an example, the different off-centering of the optical sensors of the detector may simply be a starting point for movement of the optical sensors relative to the optical axis such that the light spot is off-centered with respect to the optical axis and with respect to a geometrical center of the array of the optical sensors.

Thus, generally, the optical sensors of the detector may form a sensor array or may be part of a sensor array, such as the above-mentioned quadrant diode. Thus, as an example, the detector may comprise an array of optical sensors, such as a rectangular array, having m rows and n columns, with m, n, independently, being positive integers. Preferably, more than one column and more than one row is given, i.e. $n>1$, $m>1$. Thus, as an example, n may be 2 to 16 or higher and m may be 2 to 16 or higher. Preferably, the ratio of the number of rows and the number of columns is close to 1. As an example, n and m may be selected such that $0.3 \leq m/n \leq 3$, such as by choosing m/n = 1:1, 4:3, 16:9 or similar. As an example, the array may be a square array, having an equal number of rows and columns, such as by choosing m=2, n=2 or m=3, n=3 or

the like. The case m=2, n=2 is the case of the quadrant diode or quadrant optical sensor, which, for practical reasons, is one of the preferred cases, since quadrant photodiodes are widely available.

As a starting point, a geometrical center of the optical sensors within the array may be off-centered from the optical axis, such as by the above-mentioned offset. The sensor array specifically may be movable relative to the optical axis, for example along a gradient, preferably automatically, such as by moving the sensor array, e.g. in a plane perpendicular to the optical axis, and/or by moving the optical axis itself, e.g. shifting the optical axis in a parallel shift and/or tilting the optical axis. Thus, the sensor array may be shifted in order to adjust a position of a light spot generated by the light beam in the plane of the sensor array. Additionally or alternatively, the optical axis may be shifted and/or tilted by using appropriate elements, such as by using one or more deflection elements and/or one or more lenses. The movement, as an example, may take place by using one or more appropriate actuators, such as one or more piezo actuators and/or one or more electromagnetic actuators and/or one or more pneumatic or mechanical actuators, which, e.g., move and/or shift the array and/or move and/or shift and/or tillage one or more optical elements in the beam path in order to move the optical axis, such as parallel shifting the optical axis and/or tilting the optical axis. The evaluation device specifically may be adjusted to control a relative position of the sensor array to the optical axis, e.g. in the plane perpendicular to the optical axis. An adjustment procedure may take place in that the evaluation device is configured for, firstly, determining the at least one transversal position of a light spot generated by the light beam on the sensor array by using the sensor signals and for, secondly, moving the array relative to the optical axis, such as by moving the array and/or the optical axis, e.g. by moving the array in the plane to the optical axis until the light spot is off-centered and/or by tilting a lens until the light spot is off-centered. As used therein, a transversal position may be a position in a plane perpendicular to the optical axis, which may also be referred to as the x-y-plane. For the measurement of the transversal coordinate, as an example, the sensor signals of the optical sensors may be compared. As an example, in case the sensor signals are found to be equal and, thus, in case it is determined that the light spot is located symmetrically with respect to the optical sensors, such as in the center of the quadrant diodes, a shifting of the array and/or a tilting of a lens may take place, in order to off-center the light spot in the array. Thus, as outlined above, the off-centering of the array from the optical axis, such as by off-centering the center of the quadrant photodiode from the optical axis, may simply be a starting point in order to avoid the situation which is typical, in which the light spot is located on the optical axis and, thus, is centered. By off-centering the array relative to the optical axis, thus, the light spot should be off-centered. In case this is found not to be true, such that the light spot, incidentally, is located in the center of the array and equally illuminates all optical sensors, the above-mentioned shifting of the array relative to the optical axis may take place, preferably automatically, in order to off-center the light spot on the array. Thereby, a reliable distance measurement may take place.

Further, in a scanning system with a movable light source, the position of the light spot on the quadrant diode may not be fixed. This is still possible, but may necessitate that different calibrations are used, dependent on the xy-position of the spot in the diode.

Further, the use of the above-mentioned first combined signal Q is a very reliable method for distance measurements. Typically, Q is a monotonous function of the longitudinal coordinate of the object and/or of the size of the light spot such as the diameter or equivalent diameter of the light spot. Thus, as an example, specifically in case linear optical sensors are used, the combined signal $Q=s_1/s_2$ is a monotonously decreasing function of the size of the light spot. Without wishing to be bound by this theory, it is believed that this is due to the fact that, in the preferred setup described above, the second sensor signals, such as the above-mentioned first sensor signal of the second sensor signals s_1 and the above-mentioned second sensor signal of the second sensor signals s_2, decrease as a square function with increasing distance to the light source, since the amount of light reaching the detector decreases. Therein, however, due to the off-centering, the one of the second sensor signals decreases more rapidly than the other, since, in the optical setup as used in the experiments, the light spot in the image plane grows and, thus, is spread over a larger area. By spreading the light spot, however, the portion of the light illuminating the one or more optical sensors outside the center of the light spot increases, as compared to a situation of a very small light spot. Thus, the first combined signal of the second sensor signals continuously changes, i.e. increases or decreases, with increasing diameter of the light beam or diameter of the light spot. The first combined signal, further, may further be rendered mainly independent from the total power of the light beam, since the total power of the light beam forms a factor in all sensor signals. Consequently, the first combined signal Q may form a secondary signal which provides a unique and unambiguous relationship between the sensor signals and the size or diameter of the light beam.

Since, on the other hand, the size or diameter of the light beam is dependent on a distance between the object, from which the light beam propagates towards the detector, and the detector itself, i.e. dependent on the longitudinal coordinate of the object, a unique and unambiguous relationship between the first and second sensor signals and the longitudinal coordinate may exist. For the latter, reference e.g. may be made to one or more of the above-mentioned prior art documents, such as WO 2014/097181 A1. The predetermined relationship may be determined by analytical considerations, such as by assuming a linear combination of Gaussian light beams, by empirical measurements, such as measurements measuring the first and second sensor signals or a secondary signal derived thereof as a function of the longitudinal coordinate of the object, or both.

As outlined above, specifically, photodiode arrays may be used. As an example, commercially available multi-pixel photon counter arrays may be integrated in order to provide a plurality optical sensors, such as one or more multi-pixel photon counter arrays available from Hamamatsu Photonics Deutschland GmbH, D-82211 Herrsching am Ammersee, Germany, such as multi-pixel photon counter arrays of the type S13361-2050, which are sensitive in the UV spectral range to the near IR spectral range. In case an array of optical sensors is used, the array may

be a naked chip or may be an encapsulated array, such as encapsulated in a TO-5 metal package. Additionally or alternatively, a quadrant photodiode, such as a quadrant avalanche photodiode may be used, such as First Sensor QA4000-10 TO, available from First Sensor AG, Peter-Behrens-Straße 15, 12459 Berlin, Germany. It shall be noted that other optical sensors may also be used.

Further, it shall be noted that, besides the option of using precisely one quadrant photodiode, two or more quadrant photodiodes may also be used. Thus, as an example, a first quadrant photodiode may be used for the distance measurement, as described above, providing the two or more optical sensors. Another quadrant photodiode may be used, e.g. in a second partial beam path split off from the beam path of the first quadrant photodiode, for a transversal position measurement, such as for using at least one transversal coordinate x and/or y. The second quadrant photodiode, as an example, may be located on-axis with respect to the optical axis.

Further, it shall be noted that, besides the option of using one or more quadrant photodiodes, one or more quadrant photodiodes or further photodiode arrays may also be replaced or mimicked by separated photodiodes that are arranged or assembled close to each other, preferably in a symmetric shape such as a rectangular matrix, such as a 2 x 2 matrix. However further arrangements are feasible. In such an arrangement or assembly, the photodiodes may be arranged or assembled in a housing or mount, such as all photodiodes in a single housing or mount or groups of photodiodes in one housing or mount, or each of the photodiodes in a separate housing or mount. Further, the photodiodes may also be assembled directly on a circuit board. In such arrangements or assemblies, photodiodes may be arranged as such that the separation between the active area of the photodiodes, has a distinct value less than one centimeter, preferably less than one millimeter, more preferably as small as possible. Further, to avoid optical reflexes, distortions, or the like that may deteriorate the measurement, the space between the active areas may be either empty or filled with a material, preferably with a light absorbing material such as a black polymer, such as black silicon, black polyoxymethylene, or the like, more preferably optically absorbing and electrically insulating material, such as black ceramics or insulating black polymers such as black silicon, or the like. Further, the distinct value of the photodiode separation may also be realized by adding a distinct building block between the photodiodes such as a plastic separator. Further embodiments are feasible. The replacement of quadrant photodiodes by single diodes arranged in a similar setup such as in a 2 x 2 rectangular matrix with minimal distance between the active areas may further minimize the costs for the optical detector. Further, two or more diodes from a quadrant diode may be connected in parallel or in series to form a single light sensitive area.

In a further aspect of the present invention, a detector system for determining a position of at least one object is disclosed. The detector system comprises at least one detector according to the present invention, such as according to one or more of the embodiments disclosed above or according to one or more of the embodiments disclosed in further detail below. The detector system further comprises at least one beacon device adapted to direct at least one light beam towards the detector, wherein the beacon device is at least one of attachable to the object,

holdable by the object and integratable into the object. Further details regarding the beacon device will be given below, including potential embodiments thereof. The at least one beacon device may be adapted to reflect one or more light beams towards the detector, such as by comprising one or more reflective elements. Further, the at least one beacon device may be or may comprise one or more scattering elements adapted for scattering a light beam. Therein, elastic or inelastic scattering may be used. In case the at least one beacon device is adapted to reflect and/or scatter a primary light beam towards the detector, the beacon device may be adapted to leave the spectral properties of the light beam unaffected or, alternatively, may be adapted to change the spectral properties of the light beam, such as by modifying a wavelength of the light beam.

In a further aspect of the present invention, a human-machine interface for exchanging at least one item of information between a user and a machine is disclosed. The human-machine interface comprises at least one detector system according to the embodiments disclosed above and/or according to one or more of the embodiments disclosed in further detail below. Therein, the at least one beacon device is adapted to be at least one of directly or indirectly attached to the user or held by the user. The human-machine interface is designed to determine at least one position of the user by means of the detector system, wherein the human-machine interface is designed to assign to the position at least one item of information.

In a further aspect of the present invention, an entertainment device for carrying out at least one entertainment function is disclosed. The entertainment device comprises at least one human-machine interface according to the embodiment disclosed above and/or according to one or more of the embodiments disclosed in further detail below. The entertainment device is configured to enable at least one item of information to be input by a player by means of the human-machine interface. The entertainment device is further configured to vary the entertainment function in accordance with the information.

In a further aspect of the present invention, a tracking system for tracking a position of at least one movable object is disclosed. The tracking system comprises at least one detector system according to one or more of the embodiments referring to a detector system as disclosed above and/or as disclosed in further detail below. The tracking system further comprises at least one track controller. The track controller is adapted to track a series of positions of the object at specific points in time.

In a further aspect of the present invention, a camera for imaging at least one object is disclosed. The camera comprises at least one detector according to any one of the embodiments referring to a detector as disclosed above or as disclosed in further detail below.

In a further aspect of the present invention, a readout device for optical storage media is proposed. The readout device comprises at least one detector according to any one of the preceding embodiments referring to a detector. As used therein, a readout device for optical storage media generally refers to a device which is capable of optically retrieving information stored in

optical storage media such as optical storage discs, e.g. CCD, DVD or Blu-ray discs. Thus, the above-described measurement principle of the detector according to the present invention may be used for detecting data modules within an optical storage medium such as in optical storage discs. As an example, in case a reflective data module is present and reflects the illuminating light beam, the detector will not only detect the reflected light beam according to the above-mentioned measurement principle but will also detect a distance between the detector and the reflective data module, i.e. a depth of the reflective data module within the optical storage medium. Thus, as an example, the detector may be used for detecting different layers of information modules or data modules within the optical storage medium. Thereby, as an example, two layer discs or three layer discs or even discs having more than three layers may be generated and read out.

In a further aspect of the present invention, a scanning system for determining a depth profile of a scenery, which may also imply determining at least one position of at least one object, is provided. The scanning system comprises at least one detector according to the present invention, such as at least one detector as disclosed in one or more of the embodiments listed above and/or as disclosed in one or more of the embodiments below. The scanning system further comprises at least one illumination source adapted to scan the scenery with at least one light beam, which may also be referred to as an illumination light beam or scanning light beam. As used herein, the term “scenery” generally refers to a two-dimensional or three-dimensional range which is visible by the detector, such that at least one geometric or spatial property of the two-dimensional or three-dimensional range may be evaluated with the detector. As further used herein, the term “scan” generally refers to a consecutive measurement in different regions. Thus, the scanning specifically may imply at least one first measurement with the illumination light beam being oriented or directed in a first fashion, and at least one second measurement with the illumination light beam being oriented or directed in a second fashion which is different from the first fashion. The scanning may be a continuous scanning or a stepwise scanning. Thus, in a continuous or stepwise fashion, the illumination light beam may be directed into different regions of the scenery, and the detector may be detected to generate at least one item of information, such as at least one longitudinal coordinate, for each region. As an example, for scanning an object, one or more illumination light beams may, continuously or in a stepwise fashion, create light spots on the surface of the object, wherein longitudinal coordinates are generated for the light spots. Alternatively, however, a light pattern may be used for scanning. The scanning may be a point scanning or a line scanning or even a scanning with more complex light patterns. The illumination source of the scanning system may be distinct from the optional illumination source of the detector. Alternatively, however, the illumination source of the scanning system may also be fully or partially identical with or integrated into the at least one optional illumination source of the detector.

Thus, the scanning system may comprise at least one illumination source which is adapted to emit the at least one light beam being configured for the illumination of the at least one dot located at the at least one surface of the at least one object. As used herein, the term “dot” refers to an area, specifically a small area, on a part of the surface of the object which may be select-

ed, for example by a user of the scanning system, to be illuminated by the illumination source. Preferably, the dot may exhibit a size which may, on one hand, be as small as possible in order to allow the scanning system to determine a value for the distance between the illumination source comprised by the scanning system and the part of the surface of the object on which the dot may be located as exactly as possible and which, on the other hand, may be as large as possible in order to allow the user of the scanning system or the scanning system itself, in particular by an automatic procedure, to detect a presence of the dot on the related part of the surface of the object.

For this purpose, the illumination source may comprise an artificial illumination source, in particular at least one laser source and/or at least one incandescent lamp and/or at least one semiconductor light source, for example, at least one light-emitting diode, in particular an organic and/or inorganic light-emitting diode. As an example, the light emitted by the illumination source may have a wavelength of 300-500 nm. Additionally or alternatively, light in the infrared spectral range may be used, such as in the range of 780 nm to 3.0 µm. Specifically, the light in the part of the near infrared region where silicon photodiodes are applicable specifically in the range of 700 nm to 1000 nm may be used. On account of their generally defined beam profiles and other properties of handleability, the use of at least one laser source as the illumination source is particularly preferred. Herein, the use of a single laser source may be preferred, in particular in a case in which it may be important to provide a compact scanning system that might be easily storable and transportable by the user. The illumination source may thus, preferably be a constituent part of the detector and may, therefore, in particular be integrated into the detector, such as into the housing of the detector. In a preferred embodiment, particularly the housing of the scanning system may comprise at least one display configured for providing distance-related information to the user, such as in an easy-to-read manner. In a further preferred embodiment, particularly the housing of the scanning system may, in addition, comprise at least one button which may be configured for operating at least one function related to the scanning system, such as for setting one or more operation modes. In a further preferred embodiment, particularly the housing of the scanning system may, in addition, comprise at least one fastening unit which may be configured for fastening the scanning system to a further surface, such as a rubber foot, a base plate or a wall holder, such as a base plate or holder comprising a magnetic material, in particular for increasing the accuracy of the distance measurement and/or the handleability of the scanning system by the user.

Particularly, the illumination source of the scanning system may, thus, emit a single laser beam which may be configured for the illumination of a single dot located at the surface of the object. By using at least one of the detectors according to the present invention at least one item of information about the distance between the at least one dot and the scanning system may, thus, be generated. Hereby, preferably, the distance between the illumination system as comprised by the scanning system and the single dot as generated by the illumination source may be determined, such as by employing the evaluation device as comprised by the at least one detector. However, the scanning system may, further, comprise an additional evaluation system which may, particularly, be adapted for this purpose. Alternatively or in addition, a size of the

scanning system, in particular of the housing of the scanning system, may be taken into account and, thus, the distance between a specific point on the housing of the scanning system, such as a front edge or a back edge of the housing, and the single dot may, alternatively, be determined. The illumination source may be adapted to generate and/or to project a cloud of points, for example the illumination source may comprise one or more of at least one digital light processing (DLP) projector, at least one LCoS projector, at least one spatial light modulator; at least one diffractive optical element; at least one array of light emitting diodes; at least one array of laser light sources.

Alternatively, the illumination source of the scanning system may emit two individual laser beams which may be configured for providing a respective angle, such as a right angle, between the directions of an emission of the beams, whereby two respective dots located at the surface of the same object or at two different surfaces at two separate objects may be illuminated. However, other values for the respective angle between the two individual laser beams may also be feasible. This feature may, in particular, be employed for indirect measuring functions, such as for deriving an indirect distance which may not be directly accessible, such as due to a presence of one or more obstacles between the scanning system and the dot or which may otherwise be hard to reach. By way of example, it may, thus, be feasible to determine a value for a height of an object by measuring two individual distances and deriving the height by using the Pythagoras formula. In particular for being able to keep a predefined level with respect to the object, the scanning system may, further, comprise at least one leveling unit, in particular an integrated bubble vial, which may be used for keeping the predefined level by the user.

As a further alternative, the illumination source of the scanning system may emit a plurality of individual laser beams, such as an array of laser beams which may exhibit a respective pitch, in particular a regular pitch, with respect to each other and which may be arranged in a manner in order to generate an array of dots located on the at least one surface of the at least one object. For this purpose, specially adapted optical elements, such as beam-splitting devices and mirrors, may be provided which may allow a generation of the described array of the laser beams. In particular, the illumination source may be directed to scan an area or a volume by using one or more movable mirrors to redirect the light beam in a periodic or non-periodic fashion. Thus, the scanning system may provide a static arrangement of the one or more dots placed on the one or more surfaces of the one or more objects. Alternatively, the illumination source of the scanning system, in particular the one or more laser beams, such as the above described array of the laser beams, may be configured for providing one or more light beams which may exhibit a varying intensity over time and/or which may be subject to an alternating direction of emission in a passage of time, in particular by moving one or more mirrors, such as the micro-mirrors comprised within the mentioned array of micro-mirrors. As a result, the illumination source may be configured for scanning a part of the at least one surface of the at least one object as an image by using one or more light beams with alternating features as generated by the at least one illumination source of the scanning device. In particular, the scanning system may, thus, use at least one row scan and/or line scan, such as to scan the one or more surfaces of the one or more objects sequentially or simultaneously. Thus, the scanning system may be adapted to

measure angles by measuring three or more dots, or the scanning system may be adapted to measure corners or narrow regions such as a gable of a roof, which may be hardly accessible using a conventional measuring stick. As non-limiting examples, the scanning system may be used in safety laser scanners, e.g. in production environments, and/or in 3D-scanning devices as used for determining the shape of an object, such as in connection to 3D-printing, body scanning, quality control, in construction applications, e.g. as range meters, in logistics applications, e.g. for determining the size or volume of a parcel, in household applications, e.g. in robotic vacuum cleaners or lawn mowers, or in other kinds of applications which may include a scanning step. As non-limiting examples, the scanning system may be used in industrial safety curtain applications. As non-limiting examples, the scanning system may be used to perform sweeping, vacuuming, mopping, or waxing functions, or yard or garden care functions such as mowing or raking. As non-limiting examples, the scanning system may employ an LED illumination source with collimated optics and may be adapted to shift the frequency of the illumination source to a different frequency to obtain more accurate results and/or employ a filter to attenuate certain frequencies while transmitting others. As non-limiting examples, the scanning system and/or the illumination source may be rotated as a whole or rotating only a particular optics package such as a mirror, beam splitter or the like, using a dedicated motor as such that in operation, the scanning system may have a full 360 degree view or even be moved and or rotated out of plane to further increase the scanned area. Further, the illumination source may be actively aimed in a predetermined direction. Further, to allow the rotation of wired electrical systems, slip rings, optical data transmission, or inductive couplings may be employed.

As a non-limiting example, the scanning system may be attached to a tripod and point towards an object or region with a several corners and surfaces. One or more flexibly movable laser sources are attached to the scanning system. The one or more laser sources are moved as such that they illuminate points of interest. The position of the illuminated points with respect to the scanning system is measured when pressing a designated button on the scanning system and the position information is transmitted via a wireless interface to a mobile phone. The position information is stored in a mobile phone application. The laser sources are moved to illuminate further points of interest the position of which are measured and transmitted to the mobile phone application. The mobile phone application may transform the set of points into a 3d model by connecting adjacent points with planar surfaces. The 3d model may be stored and processed further. The distances and or angles between the measured points or surfaces may be displayed directly on a display attached to a scanning system or on the mobile phone to which the position information is transmitted.

As a non-limiting example, a scanning system may comprise two or more flexible movable laser sources to project points and further one movable laser source projecting a line. The line may be used to arrange the two or more laser spots along a line and the display of the scanning device may display the distance between the two or more laser spots that may be arranged along the line, such as at equal distance. In the case of two laser spots, a single laser source may be used whereas the distance of the projected points is modified using one or more beam-splitters or prisms, where a beam-splitter or prism can be moved as such that the projected laser spots

move apart or closer together. Further, the scanning system may be adapted to project further patterns such as a right angle, a circle, a square, a triangle, or the like, along which a measurement can be done by projecting laser spots and measuring their position.

As a non-limiting example, the scanning system may be adapted to support the work with tools, such as wood or metal processing tools, such as a saw, a driller, or the like. Thus, the scanning system may be adapted to measure the distance in two opposite directions and display the two measured distances or the sum of the distances in a display. Further, the scanning system may be adapted to measure the distance to the edge of a surface as such that when the scanning system is placed on the surface, a laser point is moved automatically away from the scanning system along the surface, until the distance measurement shows a sudden change due to a corner or the edge of a surface. This makes it possible to measure the distance of the end of a wood plank while the scanning device is placed on the plank but remote from its end. Further, the scanning system may measure the distance of the end of a plank in one direction and project a line or circle or point in a designated distance in the opposite direction. The scanning system may be adapted to project the line or circle or point in a distance depending on the distance measured in the opposite direction such as depending on a predetermined sum distance. This allows working with a tool such as a saw or driller at the projected position while placing the scanning system in a safe distance from the tool and simultaneously perform a process using the tool in a predetermined distance to the edge of the plank. Further, the scanning system may be adapted to project points or lines or the like in two opposite directions in a predetermined distance. When the sum of the distances is changed, only one of the projected distances changes.

As a non-limiting example, the scanning system may be adapted to be placed onto a surface, such as a surface on which a task is performed, such as cutting, sawing, drilling, or the like, and to project a line onto the surface in a predetermined distance that can be adjusted such as with buttons on the scanning device.

As non-limiting examples, the scanning system may be used in safety laser scanners, e.g. in production environments, and/or in 3D-scanning devices as used for determining the shape of an object, such as in connection to 3D-printing, body scanning, quality control, in construction applications, e.g. as range meters, in logistics applications, e.g. for determining the size or volume of a parcel, in household applications, e.g. in robotic vacuum cleaners or lawn mowers, or in other kinds of applications which may include a scanning step.

The transfer device can, as explained above, be designed to feed light propagating from the object to the detector to the optical sensor, preferably successively. As explained above, this feeding can optionally be effected by means of imaging or else by means of non-imaging properties of the transfer device. In particular the transfer device can also be designed to collect the electromagnetic radiation before the latter is fed to the optical sensor. The transfer device can also be wholly or partly a constituent part of at least one optional illumination source, for example by the illumination source being designed to provide a light beam having defined optical

properties, for example having a defined or precisely known beam profile, for example at least one linear combination of Gaussian beams, in particular at least one laser beam having a known beam profile.

For potential embodiments of the optional illumination source, reference may be made to WO 2012/110924 A1. Still, other embodiments are feasible. Light emerging from the object can originate in the object itself, but can also optionally have a different origin and propagate from this origin to the object and subsequently toward the transversal and/or longitudinal optical sensor. The latter case can be effected for example by at least one illumination source being used. This illumination source can for example be or comprise an ambient illumination source and/or may be or may comprise an artificial illumination source. By way of example, the detector itself can comprise at least one illumination source, for example at least one laser and/or at least one incandescent lamp and/or at least one semiconductor illumination source, for example, at least one light-emitting diode, in particular an organic and/or inorganic light-emitting diode. On account of their generally defined beam profiles and other properties of handleability, the use of one or a plurality of lasers as illumination source or as part thereof, is particularly preferred. The illumination source itself can be a constituent part of the detector or else be formed independently of the detector. The illumination source can be integrated in particular into the detector, for example a housing of the detector. Alternatively or additionally, at least one illumination source can also be integrated into the at least one beacon device or into one or more of the beacon devices and/or into the object or connected or spatially coupled to the object.

The light emerging from the one or more optional beacon devices can accordingly, alternatively or additionally from the option that said light originates in the respective beacon device itself, emerge from the illumination source and/or be excited by the illumination source. By way of example, the electromagnetic light emerging from the beacon device can be emitted by the beacon device itself and/or be reflected by the beacon device and/or be scattered by the beacon device before it is fed to the detector. In this case, emission and/or scattering of the electromagnetic radiation can be effected without spectral influencing of the electromagnetic radiation or with such influencing. Thus, by way of example, a wavelength shift can also occur during scattering, for example according to Stokes or Raman. Furthermore, emission of light can be excited, for example, by a primary illumination source, for example by the object or a partial region of the object being excited to generate luminescence, in particular phosphorescence and/or fluorescence. Other emission processes are also possible, in principle. If a reflection occurs, then the object can have for example at least one reflective region, in particular at least one reflective surface. Said reflective surface can be a part of the object itself, but can also be for example a reflector which is connected or spatially coupled to the object, for example a reflector plaque connected to the object. If at least one reflector is used, then it can in turn also be regarded as part of the detector which is connected to the object, for example, independently of other constituent parts of the detector.

The at least one optional illumination source generally may emit light in at least one of: the ultraviolet spectral range, preferably in the range of 200 nm to 380 nm; the visible spectral range

(380 nm to 780 nm); the infrared spectral range, preferably in the range of 780 nm to 3.0 micrometers, more preferably in the part of the near infrared region where silicon photodiodes are applicable specifically in the range of 700 nm to 1000 nm. For thermal imaging applications the target may emit light in the far infrared spectral range, preferably in the range of 3.0 micrometers to 20 micrometers. For example, the at least one illumination source is adapted to emit light in the visible spectral range, preferably in the range of 500 nm to 780 nm, most preferably at 650 nm to 750 nm or at 690 nm to 700 nm. For example, the at least one illumination source is adapted to emit light in the infrared spectral range. Other options, however, are feasible.

The feeding of the light beam to the optical sensor can be effected in particular in such a way that a light spot, for example having a round, oval or differently configured cross section, is produced on the optional sensor area of the optical sensor. By way of example, the detector can have a visual range, in particular a solid angle range and/or spatial range, within which objects can be detected. Preferably, the transfer device may be designed in such a way that the light spot, for example in the case of an object arranged within a visual range of the detector, is arranged completely on a sensor region and/or on a sensor area of the optical sensor. By way of example, a sensor area can be chosen to have a corresponding size in order to ensure this condition.

In a further aspect, the present invention discloses a method for determining a position of at least one object by using a detector, such as a detector according to the present invention, such as according to one or more of the embodiments referring to a detector as disclosed above or as disclosed in further detail below. Still, other types of detectors may be used. The method comprises the following method steps, wherein the method steps may be performed in the given order or may be performed in a different order. Further, one or more additional method steps may be present which are not listed. Further, one, more than one or even all of the method steps may be performed repeatedly.

The method comprises the following method steps:

- illuminating the object with at least one illumination light beam;
- providing a plurality of optical sensors, each optical sensor having a light-sensitive area, wherein at least one of the optical sensor is configured to generate a first sensor signal in response to an illumination of its respective light-sensitive area by a reflection light beam from the object, wherein the first sensor signal comprises at least one information about a first distance from the object to the light sensitive area of the optical sensor, wherein at least two of the optical sensors are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam, wherein each of the second sensor signal comprises at least one information about a beam profile of the reflection light beam impinging on the light sensitive area;
- illuminating the light-sensitive area of the at least one optical sensor adapted to generate the first sensor signal with the reflection light beam, wherein, thereby, the light-sensitive area generates the at least one first sensor signal;

- illuminating each of the light-sensitive areas of the at least two optical sensors adapted to generate the second sensor signal, wherein, thereby, each of the light-sensitive areas generates at least one second sensor signal; and
- evaluating the first sensor signal, thereby, determining at least one first longitudinal coordinate z_1 of the object,
- evaluating the second sensor signals, thereby, determining at least one second longitudinal coordinate z_2, wherein the evaluating comprises deriving a first combined signal Q of the second sensor signals.

The deriving of the first combined signal Q may comprise one or more of dividing the sensor signals, dividing multiples of the sensor signals, dividing linear combinations of the sensor signals. For details, options and definitions, reference may be made to the detector as discussed above. Thus, specifically, as outlined above, the method may comprise using the detector according to the present invention, such as according to one or more of the embodiments given above or given in further detail below.

In a further aspect of the present invention, use of the detector according to the present invention, such as according to one or more of the embodiments given above or given in further detail below, is proposed, for a purpose of use, selected from the group consisting of: a position measurement in traffic technology; an entertainment application; an optical data storage application; a security application; a surveillance application; a safety application; a human-machine interface application; a tracking application; a photography application; an imaging application or camera application; a mapping application for generating maps of at least one space; a homing or tracking beacon detector for vehicles; a machine vision application; a robotics application; a quality control application; a manufacturing application.

For example, the detector may be used for safety applications such as for enhancing safety integrity levels. Safety applications for risk reduction, such as for ensuring switching off machines in case of risks for a user, may use different safety integrity levels, for example a warning-level and a switching-off-level. The different safety integrity levels may be chosen with respect to a distance between the machine and the user. The distance at which the machine is switched off is often predefined by a detectable distance of the ToF-scanner. The detector according to the present invention may allow further reducing the distance at which the machine is switched off.

The object generally may be a living or non-living object. The detector or the detector system even may comprise the at least one object, the object thereby forming part of the detector system. Preferably, however, the object may move independently from the detector, in at least one spatial dimension. The object generally may be an arbitrary object. In one embodiment, the object may be a rigid object. Other embodiments are feasible, such as embodiments in which the object is a non-rigid object or an object which may change its shape.

As will be outlined in further detail below, the present invention may specifically be used for tracking positions and/or motions of a person, such as for the purpose of controlling machines, gaming or simulation of sports. In this or other embodiments, specifically, the object may be selected from the group consisting of: an article of sports equipment, preferably an article selected from the group consisting of a racket, a club, a bat; an article of clothing; a hat; a shoe.

Thus, generally, the devices according to the present invention, such as the detector, may be applied in various fields of uses. Specifically, the detector may be applied for a purpose of use, selected from the group consisting of: a position measurement in traffic technology; an entertainment application; a security application; a human-machine interface application; a tracking application; a photography application; a mapping application for generating maps of at least one space, such as at least one space selected from the group of a room, a building and a street; a mobile application; a webcam; an audio device; a dolby surround audio system; a computer peripheral device; a gaming application; a camera or video application; a security application; a surveillance application; an automotive application; a transport application; a medical application; a sports' application; a machine vision application; a vehicle application; an airplane application; a ship application; a spacecraft application; a building application; a construction application; a cartography application; a manufacturing application. Additionally or alternatively, applications in local and/or global positioning systems may be named, especially landmark-based positioning and/or navigation, specifically for use in cars or other vehicles (such as trains, motorcycles, bicycles, trucks for cargo transportation), robots or for use by pedestrians. Further, indoor positioning systems may be named as potential applications, such as for household applications and/or for robots used in manufacturing, logistics, surveillance, or maintenance technology.

The devices according to the present invention may be used in mobile phones, tablet computers, laptops, smart panels or other stationary or mobile or wearable computer or communication applications. Thus, the devices according to the present invention may be combined with at least one active light source, such as a light source emitting light in the visible range or infrared spectral range, in order to enhance performance. Thus, as an example, the devices according to the present invention may be used as cameras and/or sensors, such as in combination with mobile software for scanning and/or detecting environment, objects and living beings. The devices according to the present invention may even be combined with 2D cameras, such as conventional cameras, in order to increase imaging effects. The devices according to the present invention may further be used for surveillance and/or for recording purposes or as input devices to control mobile devices, especially in combination with voice and/or gesture recognition. Thus, specifically, the devices according to the present invention acting as human-machine interfaces, also referred to as input devices, may be used in mobile applications, such as for controlling other electronic devices or components via the mobile device, such as the mobile phone. As an example, the mobile application including at least one device according to the present invention may be used for controlling a television set, a game console, a music player or music device or other entertainment devices.

Further, the devices according to the present invention may be used in webcams or other peripheral devices for computing applications. Thus, as an example, the devices according to the present invention may be used in combination with software for imaging, recording, surveillance, scanning or motion detection. As outlined in the context of the human-machine interface and/or the entertainment device, the devices according to the present invention are particularly useful for giving commands by facial expressions and/or body expressions. The devices according to the present invention can be combined with other input generating devices like e.g. mouse, keyboard, touchpad, microphone etc. Further, the devices according to the present invention may be used in applications for gaming, such as by using a webcam. Further, the devices according to the present invention may be used in virtual training applications and/or video conferences. Further, devices according to the present invention may be used to recognize or track hands, arms, or objects used in a virtual or augmented reality application, especially when wearing head-mounted displays.

Further, the devices according to the present invention may be used in mobile audio devices, television devices and gaming devices, as partially explained above. Specifically, the devices according to the present invention may be used as controls or control devices for electronic devices, entertainment devices or the like. Further, the devices according to the present invention may be used for eye detection or eye tracking, such as in 2D- and 3D-display techniques, especially with transparent displays for augmented reality applications and/or for recognizing whether a display is being looked at and/or from which perspective a display is being looked at. Further, devices according to the present invention may be used to explore a room, boundaries, obstacles, in connection with a virtual or augmented reality application, especially when wearing a head-mounted display.

Further, the devices according to the present invention may be used in or as digital cameras such as DSC cameras and/or in or as reflex cameras such as SLR cameras. For these applications, reference may be made to the use of the devices according to the present invention in mobile applications such as mobile phones, as disclosed above.

Further, the devices according to the present invention may be used for security or surveillance applications. Thus, as an example, at least one device according to the present invention can be combined with one or more digital and/or analogue electronics that will give a signal if an object is within or outside a predetermined area (e.g. for surveillance applications in banks or museums). Specifically, the devices according to the present invention may be used for optical encryption. Detection by using at least one device according to the present invention can be combined with other detection devices to complement wavelengths, such as with IR, x-ray, UV-VIS, radar or ultrasound detectors. The devices according to the present invention may further be combined with an active infrared light source to allow detection in low light surroundings. Thus, generally, the devices according to the present invention may be used for an unrecognized and undetectable tracking of moving objects. Additionally, the devices according to the present invention generally are less prone to manipulations and irritations as compared to conventional devices.

Further, given the ease and accuracy of 3D detection by using the devices according to the present invention, the devices according to the present invention generally may be used for facial, body and person recognition and identification. Therein, the devices according to the present invention may be combined with other detection means for identification or personalization purposes such as passwords, finger prints, iris detection, voice recognition or other means. Thus, generally, the devices according to the present invention may be used in security devices and other personalized applications.

Further, the devices according to the present invention may be used as 3D barcode readers for product identification.

In addition to the security and surveillance applications mentioned above, the devices according to the present invention generally can be used for surveillance and monitoring of spaces and areas. Thus, the devices according to the present invention may be used for surveying and monitoring spaces and areas and, as an example, for triggering or executing alarms in case prohibited areas are violated. Thus, generally, the devices according to the present invention may be used for surveillance purposes in building surveillance or museums, optionally in combination with other types of sensors, such as in combination with motion or heat sensors, in combination with image intensifiers or image enhancement devices and/or photomultipliers. Further, the devices according to the present invention may be used in public spaces or crowded spaces to detect potentially hazardous activities such as commitment of crimes such as theft in a parking lot or unattended objects such as unattended baggage in an airport.

Further, the devices according to the present invention may advantageously be applied in camera applications such as video and camcorder applications. Thus, the devices according to the present invention may be used for motion capture and 3D-movie recording. Therein, the devices according to the present invention generally provide a large number of advantages over conventional optical devices. Thus, the devices according to the present invention generally require a lower complexity with regard to optical components. Thus, as an example, the number of lenses may be reduced as compared to conventional optical devices, such as by providing the devices according to the present invention having one lens only. Due to the reduced complexity, very compact devices are possible, such as for mobile use. Conventional optical systems having two or more lenses with high quality generally are voluminous, such as due to the general need for voluminous beam-splitters. Further, the devices according to the present invention generally may be used for focus/autofocus devices, such as autofocus cameras. Further, the devices according to the present invention may also be used in optical microscopy, especially in confocal microscopy.

Further, the devices according to the present invention generally are applicable in the technical field of automotive technology and transport technology. Thus, as an example, the devices according to the present invention may be used as distance and surveillance sensors, such as for adaptive cruise control, emergency brake assist, lane departure warning, surround view, blind

spot detection, traffic sign detection, traffic sign recognition, lane recognition, rear cross traffic alert, light source recognition for adapting the head light intensity and range depending on approaching traffic or vehicles driving ahead, adaptive frontlighting systems, automatic control of high beam head lights, adaptive cut-off lights in front light systems, glare-free high beam front lighting systems, marking animals, obstacles, or the like by headlight illumination, rear cross traffic alert, and other driver assistance systems such as advanced driver assistance systems, or other automotive and traffic applications. Further, devices according to the present invention may be used in driver assistance systems anticipating maneuvers of the driver beforehand for collision avoidance or the like. Further, the devices according to the present invention can also be used for velocity and/or acceleration measurements, such as by analyzing a first and second time-derivative of position information gained by using the detector according to the present invention. This feature generally may be applicable in automotive technology, transportation technology or general traffic technology. Applications in other fields of technology are feasible. A specific application in an indoor positioning system may be the detection of positioning of passengers in transportation, more specifically to electronically control the use of safety systems such as airbags. The use of an airbag may be prevented in case the passenger is located as such, that the use of an airbag will cause a severe injury. Further, in vehicles such as cars, trains, planes or the like, especially in autonomous vehicles, devices according to the present invention may be used to determine whether a driver pays attention to the traffic or is distracted, or asleep, or tired, or incapable of driving such as due to the consumption of alcohol or the like.

In these or other applications, generally, the devices according to the present invention may be used as standalone devices or in combination with other sensor devices, such as in combination with radar and/or ultrasonic devices. Specifically, the devices according to the present invention may be used for autonomous driving and safety issues. Further, in these applications, the devices according to the present invention may be used in combination with infrared sensors, radar sensors, which are sonic sensors, two-dimensional cameras or other types of sensors. In these applications, the generally passive nature of the devices according to the present invention is advantageous. Thus, since the devices according to the present invention generally do not require emitting signals, the risk of interference of active sensor signals with other signal sources may be avoided. The devices according to the present invention specifically may be used in combination with recognition software, such as standard image recognition software. Thus, signals and data as provided by the devices according to the present invention typically are readily processable and, therefore, generally require lower calculation power than established 3D measurement systems. Given the low space demand, the devices according to the present invention such as cameras may be placed at virtually any place in a vehicle, such as on or behind a window screen, on a front hood, on bumpers, on lights, on mirrors or other places and the like. Various detectors according to the present invention such as one or more detectors based on the effect disclosed within the present invention can be combined, such as in order to allow autonomously driving vehicles or in order to increase the performance of active safety concepts. Thus, various devices according to the present invention may be combined with one or more other devices according to the present invention and/or conventional sensors,

such as in the windows like rear window, handgrip, side window or front window, on the bumpers or on the lights.

A combination of at least one device according to the present invention such as at least one detector according to the present invention with one or more rain detection sensors is also possible. This is due to the fact that the devices according to the present invention generally are advantageous over conventional sensor techniques such as radar, specifically during heavy rain. A combination of at least one device according to the present invention with at least one conventional sensing technique such as radar may allow for a software to pick the right combination of signals according to the weather conditions.

Further, the devices according to the present invention generally may be used as break assist and/or parking assist and/or for speed measurements. Speed measurements can be integrated in the vehicle or may be used outside the vehicle, such as in order to measure the speed of other cars in traffic control. Further, the devices according to the present invention may be used for detecting free parking spaces in parking lots. Further, the devices according to the present invention may be used in towing robots such as in automated parking lots.

Further, the devices according to the present invention may be used in the fields of medical systems and sports. Thus, in the field of medical technology, surgery robotics, e.g. for use in endoscopes, may be named, since, as outlined above, the devices according to the present invention may require a low volume only and may be integrated into other devices. Specifically, the devices according to the present invention having one lens, at most, may be used for capturing 3D information in medical devices such as in endoscopes. Further, the devices according to the present invention may be combined with an appropriate monitoring software, in order to enable tracking and analysis of movements. This may allow an instant overlay of the position of a medical device, such as an endoscope or a scalpel, with results from medical imaging, such as obtained from magnetic resonance imaging, x-ray imaging, or ultrasound imaging. These applications are specifically valuable e.g. in medical treatments where precise location information is important such as in brain surgery and long-distance diagnosis and tele-medicine. Further, the devices according to the present invention may be used in 3D-body scanning. Body scanning may be applied in a medical context, such as in dental surgery, plastic surgery, bariatric surgery, or cosmetic plastic surgery, or it may be applied in the context of medical diagnosis such as in the diagnosis of myofascial pain syndrome, cancer, body dysmorphic disorder, or further diseases. Body scanning may further be applied in the field of sports to assess ergonomic use or fit of sports equipment. Further, the devices according to the present invention may be used in wearable robots such as in exoskeletons or prosthesis or the like.

Body scanning may further be used in the context of clothing, such as to determine a suitable size and fitting of clothes. This technology may be used in the context of tailor-made clothes or in the context of ordering clothes or shoes from the internet or at a self-service shopping device such as a micro kiosk device or customer concierge device. Body scanning in the context of clothing is especially important for scanning fully dressed customers.

Further, the devices according to the present invention may be used in the context of people counting systems, such as to count the number of people in an elevator, a train, a bus, a car, or a plane, or to count the number of people passing a hallway, a door, an aisle, a retail store, a stadium, an entertainment venue, a museum, a library, a public location, a cinema, a theater, or the like. Further, the 3D-function in the people counting system may be used to obtain or estimate further information about the people that are counted such as height, weight, age, physical fitness, or the like. This information may be used for business intelligence metrics, and/or for further optimizing the locality where people may be counted to make it more attractive or safe. In a retail environment, the devices according to the present invention in the context of people counting may be used to recognize returning customers or cross shoppers, to assess shopping behavior, to assess the percentage of visitors that make purchases, to optimize staff shifts, or to monitor the costs of a shopping mall per visitor. Further, people counting systems may be used for anthropometric surveys. Further, the devices according to the present invention may be used in public transportation systems for automatically charging passengers depending on the length of transport. Further, the devices according to the present invention may be used in playgrounds for children, to recognize injured children or children engaged in dangerous activities, to allow additional interaction with playground toys, to ensure safe use of playground toys or the like.

Further the devices according to the present invention may be used in construction tools, such as a range meter that determines the distance to an object or to a wall, to assess whether a surface is planar, to align objects or place objects in an ordered manner, or in inspection cameras for use in construction environments or the like.

Further, the devices according to the present invention may be applied in the field of sports and exercising, such as for training, remote instructions or competition purposes. Specifically, the devices according to the present invention may be applied in the fields of dancing, aerobic, football, soccer, basketball, baseball, cricket, hockey, track and field, swimming, polo, handball, volleyball, rugby, sumo, judo, fencing, boxing, golf, car racing, laser tag, battlefield simulation etc. The devices according to the present invention can be used to detect the position of a ball, a bat, a sword, motions, etc., both in sports and in games, such as to monitor the game, support the referee or for judgment, specifically automatic judgment, of specific situations in sports, such as for judging whether a point or a goal actually was made.

Further, the devices according to the present invention may be used in the field of auto racing or car driver training or car safety training or the like to determine the position of a car or the track of a car, or the deviation from a previous track or an ideal track or the like.

The devices according to the present invention may further be used to support a practice of musical instruments, in particular remote lessons, for example lessons of string instruments, such as fiddles, violins, violas, celli, basses, harps, guitars, banjos, or ukuleles, keyboard instruments, such as pianos, organs, keyboards, harpsichords, harmoniums, or accordions, and/or

percussion instruments, such as drums, timpani, marimbas, xylophones, vibraphones, bongos, congas, timbales, djembes or tablas.

The devices according to the present invention further may be used in rehabilitation and physiotherapy, in order to encourage training and/or in order to survey and correct movements. Therein, the devices according to the present invention may also be applied for distance diagnostics.

Further, the devices according to the present invention may be applied in the field of machine vision. Thus, one or more of the devices according to the present invention may be used e.g. as a passive controlling unit for autonomous driving and or working of robots. In combination with moving robots, the devices according to the present invention may allow for autonomous movement and/or autonomous detection of failures in parts. The devices according to the present invention may also be used for manufacturing and safety surveillance, such as in order to avoid accidents including but not limited to collisions between robots, production parts and living beings. In robotics, the safe and direct interaction of humans and robots is often an issue, as robots may severely injure humans when they are not recognized. Devices according to the present invention may help robots to position objects and humans better and faster and allow a safe interaction. Given the passive nature of the devices according to the present invention, the devices according to the present invention may be advantageous over active devices and/or may be used complementary to existing solutions like radar, ultrasound, 2D cameras, IR detection etc. One particular advantage of the devices according to the present invention is the low likelihood of signal interference. Therefore multiple sensors can work at the same time in the same environment, without the risk of signal interference. Thus, the devices according to the present invention generally may be useful in highly automated production environments like e.g. but not limited to automotive, mining, steel, etc. The devices according to the present invention can also be used for quality control in production, e.g. in combination with other sensors like 2-D imaging, radar, ultrasound, IR etc., such as for quality control or other purposes. Further, the devices according to the present invention may be used for assessment of surface quality, such as for surveying the surface evenness of a product or the adherence to specified dimensions, from the range of micrometers to the range of meters. Other quality control applications are feasible. In a manufacturing environment, the devices according to the present invention are especially useful for processing natural products such as food or wood, with a complex 3-dimensional structure to avoid large amounts of waste material. Further, devices according to the present invention may be used to monitor the filling level of tanks, silos etc. Further, devices according to the present invention may be used to inspect complex products for missing parts, incomplete parts, loose parts, low quality parts, or the like, such as in automatic optical inspection, such as of printed circuit boards, inspection of assemblies or sub-assemblies, verification of engineered components, engine part inspections, wood quality inspection, label inspections, inspection of medical devices, inspection of product orientations, packaging inspections, food pack inspections, or the like.

Further, the devices according to the present invention may be used in vehicles, trains, airplanes, ships, spacecraft and other traffic applications. Thus, besides the applications men-

tioned above in the context of traffic applications, passive tracking systems for aircraft, vehicles and the like may be named. The use of at least one device according to the present invention, such as at least one detector according to the present invention, for monitoring the speed and/or the direction of moving objects is feasible. Specifically, the tracking of fast moving objects on land, sea and in the air including space may be named. The at least one device according to the present invention, such as the at least one detector according to the present invention, specifically may be mounted on a still-standing and/or on a moving device. An output signal of the at least one device according to the present invention can be combined e.g. with a guiding mechanism for autonomous or guided movement of another object. Thus, applications for avoiding collisions or for enabling collisions between the tracked and the steered object are feasible. The devices according to the present invention generally are useful and advantageous due to the low calculation power required, the instant response and due to the passive nature of the detection system which generally is more difficult to detect and to disturb as compared to active systems, like e.g. radar. The devices according to the present invention are particularly useful but not limited to e.g. speed control and air traffic control devices. Further, the devices according to the present invention may be used in automated tolling systems for road charges.

The devices according to the present invention generally may be used in passive applications. Passive applications include guidance for ships in harbors or in dangerous areas, and for aircraft when landing or starting. Wherein, fixed, known active targets may be used for precise guidance. The same can be used for vehicles driving on dangerous but well defined routes, such as mining vehicles. Further, the devices according to the present invention may be used to detect rapidly approaching objects, such as cars, trains, flying objects, animals, or the like. Further, the devices according to the present invention can be used for detecting velocities or accelerations of objects, or to predict the movement of an object by tracking one or more of its position, speed, and/or acceleration depending on time.

Further, as outlined above, the devices according to the present invention may be used in the field of gaming. Thus, the devices according to the present invention can be passive for use with multiple objects of the same or of different size, color, shape, etc., such as for movement detection in combination with software that incorporates the movement into its content. In particular, applications are feasible in implementing movements into graphical output. Further, applications of the devices according to the present invention for giving commands are feasible, such as by using one or more of the devices according to the present invention for gesture or facial recognition. The devices according to the present invention may be combined with an active system in order to work under e.g. low light conditions or in other situations in which enhancement of the surrounding conditions is required. Additionally or alternatively, a combination of one or more devices according to the present invention with one or more IR or VIS light sources is possible. A combination of a detector according to the present invention with special devices is also possible, which can be distinguished easily by the system and its software, e.g. and not limited to, a special color, shape, relative position to other devices, speed of movement, light, frequency used to modulate light sources on the device, surface properties, material used, reflection properties, transparency degree, absorption characteristics, etc. The device can,

amongst other possibilities, resemble a stick, a racket, a club, a gun, a knife, a wheel, a ring, a steering wheel, a bottle, a ball, a glass, a vase, a spoon, a fork, a cube, a dice, a figure, a puppet, a teddy, a beaker, a pedal, a switch, a glove, jewelry, a musical instrument or an auxiliary device for playing a musical instrument, such as a plectrum, a drumstick or the like. Other options are feasible.

Further, the devices according to the present invention may be used to detect and or track objects that emit light by themselves, such as due to high temperature or further light emission processes. The light emitting part may be an exhaust stream or the like. Further, the devices according to the present invention may be used to track reflecting objects and analyze the rotation or orientation of these objects.

Further, the devices according to the present invention generally may be used in the field of building, construction and cartography. Thus, generally, one or more devices according to the present invention may be used in order to measure and/or monitor environmental areas, e.g. countryside or buildings. Therein, one or more devices according to the present invention may be combined with other methods and devices or can be used solely in order to monitor progress and accuracy of building projects, changing objects, houses, etc. The devices according to the present invention can be used for generating three-dimensional models of scanned environments, in order to construct maps of rooms, streets, houses, communities or landscapes, both from ground or from air. Potential fields of application may be construction, cartography, real estate management, land surveying or the like. As an example, the devices according to the present invention may be used in drones or multicopters to monitor buildings, production sites, chimneys, agricultural production environments such as fields, production plants, or landscapes, to support rescue operations, to support work in dangerous environments, to support fire brigades in a burning location indoors or outdoors, or to find or monitor one or more persons or animals, or the like, or for entertainment purposes, such as a drone following and recording one or more persons doing sports such as skiing or cycling or the like, which could be realized by following a helmet, a mark, a beacon device, or the like. Devices according to the present invention could be used recognize obstacles, follow a predefined route, follow an edge, a pipe, a building, or the like, or to record a global or local map of the environment. Further, devices according to the present invention could be used for indoor or outdoor localization and positioning of drones, for stabilizing the height of a drone indoors where barometric pressure sensors are not accurate enough, or for the interaction of multiple drones such as concertized movements of several drones or recharging or refueling in the air or the like.

Further, the devices according to the present invention may be used within an interconnecting network of home appliances such as CHAIN (Cedec Home Appliances Interoperating Network) to interconnect, automate, and control basic appliance-related services in a home, e.g. energy or load management, remote diagnostics, pet related appliances, child related appliances, child surveillance, appliances related surveillance, support or service to elderly or ill persons, home security and/or surveillance, remote control of appliance operation, and automatic maintenance support. Further, the devices according to the present invention may be used in heating or cool-

ing systems such as an air-conditioning system, to locate which part of the room should be brought to a certain temperature or humidity, especially depending on the location of one or more persons. Further, the devices according to the present invention may be used in domestic robots, such as service or autonomous robots which may be used for household chores. The devices according to the present invention may be used for a number of different purposes, such as to avoid collisions or to map the environment, but also to identify a user, to personalize the robot's performance for a given user, for security purposes, or for gesture or facial recognition. As an example, the devices according to the present invention may be used in robotic vacuum cleaners, floor-washing robots, dry-sweeping robots, ironing robots for ironing clothes, animal litter robots, such as dog or cat litter robots, charging robot for electrical vehicles, security robots that detect intruders, robotic lawn mowers, automated pool cleaners, rain gutter cleaning robots, robotic shopping carts, luggage carrying robots, line following robots, laundry robots, ironing robots, window washing robots, toy robots, patient monitoring robots, baby monitoring robots, elderly monitoring robots, children monitoring robots, transport robots, telepresence robots, professional service robots, programmable toy robots, pathfinder robots, social robots providing company to less mobile people, following robots, smart card following robots, psychotherapy robots, or robots translating and speech to sign language or sign language to speech. In the context of less mobile people, such as elderly persons, household robots with the devices according to the present invention may be used for picking up objects, transporting objects, and interacting with the objects and the user in a safe way. Further, the devices according to the present invention may be used in humanoid robots, especially in the context of using humanoid hands to pick up or hold or place objects. Further, the devices according to the present invention may be used in combination with audio interfaces especially in combination with household robots which may serve as a digital assistant with interfaces to online or offline computer applications. Further, the devices according to the present invention may be used in robots that can control switches and buttons in industrial and household purposes. Further, the devices according to the present invention may be used in smart home robots such as Mayfield's Kuri. Further, the devices according to the present invention may be used in robots operating with hazardous materials or objects or in dangerous environments. As a non-limiting example, the devices according to the present invention may be used in robots or unmanned remote-controlled vehicles to operate with hazardous materials such as chemicals or radioactive materials especially after disasters, or with other hazardous or potentially hazardous objects such as mines, unexploded arms, or the like, or to operate in or to investigate insecure environments such as near burning objects or post disaster areas or for manned or unmanned rescue operations in the air, in the sea, underground, or the like.

Further, devices according to the present invention may be used for the inspection of adhesive beads, sealing beads, or the like, such as to recognize disruptions, slubs, contractions, asymetries, local defects, or the like. Further, devices according to the present invention may be used to count objects such as dry fruits on a conveyer belt, such as in difficult situations, such as when fruit of similar color and shape may be in direct contact with each other. Further, devices according to the present invention may be used in quality control of die cast or injection molded parts such as to ensure flawless casting or molding, recognize surface damages, worn

out toolings or the like. Further, devices according to the present invention may be used for laserscribing such as for quality control and positioning of the laser. Further, devices according to the present invention may be used for sorting systems, such as to detect position, rotation, and shape of an object, compare it to a database of objects, and classify the object. Further, devices according to the present invention may be used for stamping part inspection, packaging inspection, such as food and pharma packaging inspection, filament inspection, or the like.

Further, devices according to the present invention may be used for navigation purposes, where Global Positioning Systems are not sufficiently reliable. GPS signals commonly use radio waves that are can be blocked or difficult to receive indoors or outdoors in valleys or in forests below the treeline. Further, especially in unmanned autonomous vehicles, the weight of the system may be critical. Especially unmanned autonomous vehicles need high-speed position data for reliable feedback and stability of their control systems. Using devices according to the present invention may allow short time response and positioning without adding weight due to a heavy device.

Further, the devices according to the present invention may be used in household, mobile or entertainment devices, such as a refrigerator, a microwave, a washing machine, a window blind or shutter, a household alarm, an air condition devices, a heating device, a television, an audio device, a smart watch, a mobile phone, a phone, a dishwasher, a stove or the like, to detect the presence of a person, to monitor the contents or function of the device, or to interact with the person and/or share information about the person with further household, mobile or entertainment devices.

Further, the devices according to the present invention may be used to support elderly or disabled persons or persons with limited or no vision, such as in household chores or at work such as in devices for holding, carrying, or picking objects, or in a safety system with optical or acoustical signals signaling obstacles in the environment.

The devices according to the present invention may further be used in agriculture, for example to detect and sort out vermin, weeds, and/or infected crop plants, fully or in parts, wherein crop plants may be infected by fungus or insects. Further, for harvesting crops, the devices according to the present invention may be used to detect animals, such as deer, which may otherwise be harmed by harvesting devices. Further, the devices according to the present invention may be used to monitor the growth of plants in a field or greenhouse, in particular to adjust the amount of water or fertilizer or crop protection products for a given region in the field or greenhouse or even for a given plant. Further, in agricultural biotechnology, the devices according to the present invention may be used to monitor the size and shape of plants.
Further, devices according to the present invention may be used to guide users during a shaving, hair cutting, or cosmetics procedure, or the like. Further, devices according to the present invention may be used to record or monitor what is played on an instrument, such as a violin. Further, devices according to the present invention may be used in smart household appliances such as a smart refrigerator, such as to monitor the contents of the refrigerator and transmit

notifications depending on the contents. Further, devices according to the present invention may be used for monitoring or tracking populations of humans, animals, or plants, such as dear or tree populations in forests. Further, devices according to the present invention may be used in harvesting machines, such as for harvesting crops, flowers or fruits, such as grapes, corn, hops, apples, grains, rice, strawberries, asparagus, tulips, roses, soy beans, or the like. Further, devices according to the present invention may be used to monitor the growth of plants, animals, algae, fish, or the like, such as in breeding, food production, agriculture or research applications, to control irrigation, fertilization, humidity, temperature, use of herbicides, insecticides, fungicides, rodenticides, or the like. Further, devices according to the present invention may be used in feeding machines for animals or pets, such as for cows, pigs, cats, dogs, birds, fish, or the like. Further, devices according to the present invention may be used in animal product production processes, such as for collecting milk, eggs, fur, meat, or the like, such as in automated milking or butchering processes. Further, devices according to the present invention may be used for automated seeding machines, or sowing machines, or planting machines such as for planting corn, garlic, trees, salad or the like. Further, devices according to the present invention may be used to assess or monitor weather phenomena, such as clouds, fog, or the like, or to warn from danger of avalanches, tsunamis, gales, earthquakes, thunder storms, or the like. Further, devices according to the present invention may be used to measure motions, shocks, concussions, or the like such as to monitor earthquake risk. Further, devices according to the present invention may be used in traffic technology to monitor dangerous crossings, to control traffic lights depending on traffic, to monitor public spaces, to monitor roads, gyms, stadiums, ski resorts, public events, or the like. Further, devices according to the present invention may be used in medical applications such as to monitor or analyze tissues, medical or biological assays, changes in tissues such as in moles or melanoma or the like, to count bacteria, blood cells, cells, algae, or the like, for retina scans, breath or pulse measurements, gastroscopy, patient surveillance, or the like. Further, devices according to the present invention may be used to monitor the shape, size, or circumference of drops, streams, jets, or the like or to analyze, assess, or monitor profiles or gas or liquid currents such as in a wind channel, or the like. Further, devices according to the present invention may be used to warn drivers such as car or train drivers when they are getting sick or tired or the like. Further, devices according to the present invention may be used in material testing to recognize strains or tensions or fissures, or the like. Further, devices according to the present invention may be used in sailing to monitor and optimize sail positions such as automatically. Further, devices according to the present invention may be used for fuel level gauges.

Further, the devices according to the present invention may be combined with sensors to detect chemicals or pollutants, electronic nose chips, microbe sensor chips to detect bacteria or viruses or the like, Geiger counters, tactile sensors, heat sensors, or the like. This may for example be used in constructing smart robots which are configured for handling dangerous or difficult tasks, such as in treating highly infectious patients, handling or removing highly dangerous substances, cleaning highly polluted areas, such as highly radioactive areas or chemical spills, or for pest control in agriculture.

One or more devices according to the present invention can further be used for scanning of objects, such as in combination with CAD or similar software, such as for additive manufacturing and/or 3D printing. Therein, use may be made of the high dimensional accuracy of the devices according to the present invention, e.g. in x-, y- or z- direction or in any arbitrary combination of these directions, such as simultaneously. Further, the devices according to the present invention may be used in inspections and maintenance, such as pipeline inspection gauges. Further, in a production environment, the devices according to the present invention may be used to work with objects of a badly defined shape such as naturally grown objects, such as sorting vegetables or other natural products by shape or size or cutting products such as meat or objects that are manufactured with a precision that is lower than the precision needed for a processing step.

Further the devices according to the present invention may be used in local navigation systems to allow autonomously or partially autonomously moving vehicles or multicopters or the like through an indoor or outdoor space. A non-limiting example may comprise vehicles moving through an automated storage for picking up objects and placing them at a different location. Indoor navigation may further be used in shopping malls, retail stores, museums, airports, or train stations, to track the location of mobile goods, mobile devices, baggage, customers or employees, or to supply users with a location specific information, such as the current position on a map, or information on goods sold, or the like.

Further, the devices according to the present invention may be used to ensure safe driving of motorcycles such as driving assistance for motorcycles by monitoring speed, inclination, upcoming obstacles, unevenness of the road, or curves or the like. Further, the devices according to the present invention may be used in trains or trams to avoid collisions.

Further, the devices according to the present invention may be used in handheld devices, such as for scanning packaging or parcels to optimize a logistics process. Further, the devices according to the present invention may be used in further handheld devices such as personal shopping devices, RFID-readers, handheld devices for use in hospitals or health environments such as for medical use or to obtain, exchange or record patient or patient health related information, smart badges for retail or health environments, or the like.

As outlined above, the devices according to the present invention may further be used in manufacturing, quality control or identification applications, such as in product identification or size identification (such as for finding an optimal place or package, for reducing waste etc.). Further, the devices according to the present invention may be used in logistics applications. Thus, the devices according to the present invention may be used for optimized loading or packing containers or vehicles. Further, the devices according to the present invention may be used for monitoring or controlling of surface damages in the field of manufacturing, for monitoring or controlling rental objects such as rental vehicles, and/or for insurance applications, such as for assessment of damages. Further, the devices according to the present invention may be used for identifying a size of material, object or tools, such as for optimal material handling, especially in

combination with robots. Further, the devices according to the present invention may be used for process control in production, e.g. for observing filling level of tanks. Further, the devices according to the present invention may be used for maintenance of production assets like, but not limited to, tanks, pipes, reactors, tools etc. Further, the devices according to the present invention may be used for analyzing 3D-quality marks. Further, the devices according to the present invention may be used in manufacturing tailor-made goods such as tooth inlays, dental braces, prosthesis, clothes or the like. The devices according to the present invention may also be combined with one or more 3D-printers for rapid prototyping, 3D-copying or the like. Further, the devices according to the present invention may be used for detecting the shape of one or more articles, such as for anti-product piracy and for anti-counterfeiting purposes.

Thus, specifically, the present application may be applied in the field of photography. Thus, the detector may be part of a photographic device, specifically of a digital camera. Specifically, the detector may be used for 3D photography, specifically for digital 3D photography. Thus, the detector may form a digital 3D camera or may be part of a digital 3D camera. As used herein, the term photography generally refers to the technology of acquiring image information of at least one object. As further used herein, a camera generally is a device adapted for performing photography. As further used herein, the term digital photography generally refers to the technology of acquiring image information of at least one object by using a plurality of light-sensitive elements adapted to generate electrical signals indicating an intensity and/or color of illumination, preferably digital electrical signals. As further used herein, the term 3D photography generally refers to the technology of acquiring image information of at least one object in three spatial dimensions. Accordingly, a 3D camera is a device adapted for performing 3D photography. The camera generally may be adapted for acquiring a single image, such as a single 3D image, or may be adapted for acquiring a plurality of images, such as a sequence of images. Thus, the camera may also be a video camera adapted for video applications, such as for acquiring digital video sequences.

Thus, generally, the present invention further refers to a camera, specifically a digital camera, more specifically a 3D camera or digital 3D camera, for imaging at least one object. As outlined above, the term imaging, as used herein, generally refers to acquiring image information of at least one object. The camera comprises at least one detector according to the present invention. The camera, as outlined above, may be adapted for acquiring a single image or for acquiring a plurality of images, such as image sequence, preferably for acquiring digital video sequences. Thus, as an example, the camera may be or may comprise a video camera. In the latter case, the camera preferably comprises a data memory for storing the image sequence.

As used within the present invention, the expression “position” generally refers to at least one item of information regarding one or more of an absolute position and an orientation of one or more points of the object. Thus, specifically, the position may be determined in a coordinate system of the detector, such as in a Cartesian coordinate system. Additionally or alternatively, however, other types of coordinate systems may be used, such as polar coordinate systems and/or spherical coordinate systems.

As outlined above and as will be outlined in further detail below, the present invention preferably may be applied in the field of human-machine interfaces, in the field of sports and/or in the field of computer games. Thus, preferably, the object may be selected from the group consisting of: an article of sports equipment, preferably an article selected from the group consisting of a racket, a club, a bat, an article of clothing, a hat, a shoe. Other embodiments are feasible.

As used herein, the object generally may be an arbitrary object, chosen from a living object and a non-living object. Thus, as an example, the at least one object may comprise one or more articles and/or one or more parts of an article. Additionally or alternatively, the object may be or may comprise one or more living beings and/or one or more parts thereof, such as one or more body parts of a human being, e.g. a user, and/or an animal.

With regard to the coordinate system for determining the position of the object, which may be a coordinate system of the detector, the detector may constitute a coordinate system in which an optical axis of the detector forms the z-axis and in which, additionally, an x-axis and a y-axis may be provided which are perpendicular to the z-axis and which are perpendicular to each other. As an example, the detector and/or a part of the detector may rest at a specific point in this coordinate system, such as at the origin of this coordinate system. In this coordinate system, a direction parallel or antiparallel to the z-axis may be regarded as a longitudinal direction, and a coordinate along the z-axis may be considered a longitudinal coordinate. An arbitrary direction perpendicular to the longitudinal direction may be considered a transversal direction, and an x- and/or y-coordinate may be considered a transversal coordinate.

Alternatively, other types of coordinate systems may be used. Thus, as an example, a polar coordinate system may be used in which the optical axis forms a z-axis and in which a distance from the z-axis and a polar angle may be used as additional coordinates. Again, a direction parallel or antiparallel to the z-axis may be considered a longitudinal direction, and a coordinate along the z-axis may be considered a longitudinal coordinate. Any direction perpendicular to the z-axis may be considered a transversal direction, and the polar coordinate and/or the polar angle may be considered a transversal coordinate.

The detector may be a device configured for providing at least one item of information on the position of the at least one object and/or a part thereof. Thus, the position may refer to an item of information fully describing the position of the object or a part thereof, preferably in the coordinate system of the detector, or may refer to a partial information, which only partially describes the position. The detector generally may be a device adapted for detecting light beams, such as the light beams propagating from the beacon devices towards the detector.

The evaluation device and the detector may fully or partially be integrated into a single device. Thus, generally, the evaluation device also may form part of the detector. Alternatively, the evaluation device and the detector may fully or partially be embodied as separate devices. The detector may comprise further components.

The detector may be a stationary device or a mobile device. Further, the detector may be a stand-alone device or may form part of another device, such as a computer, a vehicle or any other device. Further, the detector may be a hand-held device. Other embodiments of the detector are feasible.

The detector specifically may be used to record a light-field behind a lens or lens system of the detector, comparable to a plenoptic or light-field camera. Thus, specifically, the detector may be embodied as a light-field camera adapted for acquiring images in multiple focal planes, such as simultaneously. The term light-field, as used herein, generally refers to the spatial light propagation of light inside the detector such as inside camera. The detector according to the present invention, specifically having a stack of optical sensors, may have the capability of directly recording a light-field within the detector or camera, such as behind a lens. The plurality of sensors may record images at different distances from the lens. Using, e.g., convolution-based algorithms such as “depth from focus” or “depth from defocus”, the propagation direction, focus points, and spread of the light behind the lens can be modeled. From the modeled propagation of light behind the lens, images at various distances to the lens can be extracted, the depth of field can be optimized, pictures that are in focus at various distances can be extracted, or distances of objects can be calculated. Further information may be extracted.

The use of several optical sensors further allows for correcting lens errors in an image processing step after recording the images. Optical instruments often become expensive and challenging in construction, when lens errors need to be corrected. These are especially problematic in microscopes and telescopes. In microscopes, a typical lens error is that rays of varying distance to the optical axis are distorted differently (spherical aberration). In telescopes, varying the focus may occur from differing temperatures in the atmosphere. Static errors such as spherical aberration or further errors from production may be corrected by determining the errors in a calibration step and then using a fixed image processing such as fixed set of pixels and sensor, or more involved processing techniques using light propagation information. In cases in which lens errors are strongly time-dependent, i.e. dependent on weather conditions in telescopes, the lens errors may be corrected by using the light propagation behind the lens, calculating extended depth of field images, using depth from focus techniques, and others.

The detector according to the present invention may further allow for color detection. For color detection, a plurality of optical sensors having different spectral properties may be used, and sensor signals of these optical sensors may be compared.
Further, the devices according to the present invention may be used in the context of gesture recognition. In this context, gesture recognition in combination with devices according to the present invention may, in particular, be used as a human-machine interface for transmitting information via motion of a body, of body parts or of objects to a machine. Herein, the information may, preferably, be transmitted via a motion of hands or hand parts, such as fingers, in particular, by pointing at objects, applying sign language, such as for deaf people, making signs for numbers, approval, disapproval, or the like, by waving the hand, such as when asking someone

to approach, to leave, or to greet a person, to press an object, to take an object, or, in the field of sports or music, in a hand or finger exercise, such as a warm-up exercise. Further, the information may be transmitted by motion of arms or legs, such as rotating, kicking, grabbing, twisting, rotating, scrolling, browsing, pushing, bending, punching, shaking, arms, legs, both arms, or both legs, or a combination of arms and legs, such as for a purpose of sports or music, such as for entertainment, exercise, or training function of a machine. Further, the information may be transmitted by motion of the whole body or major parts thereof, such as jumping, rotating, or making complex signs, such as sign language used at airports or by traffic police in order to transmit information, such as “turn right”, “turn left”, “proceed”, “slow down”, “stop”, or “stop engines”, or by pretending to swim, to dive, to run, to shoot, or the like, or by making complex motions or body positions such as in yoga, pilates, judo, karate, dancing, or ballet. Further, the information may be transmitted by using a real or mock-up device for controlling a virtual device corresponding to the mock-up device, such as using a mock-up guitar for controlling a virtual guitar function in a computer program, using a real guitar for controlling a virtual guitar function in a computer program, using a real or a mock-up book for reading an e-book or moving pages or browsing through in a virtual document, using a real or mock-up pen for drawing in a computer program, or the like. Further, the transmission of the information may be coupled to a feedback to the user, such as a sound, a vibration, or a motion.

In the context of music and/or instruments, devices according to the present invention in combination with gesture recognition may be used for exercising purposes, control of instruments, recording of instruments, playing or recording of music via use of a mock-up instrument or by only pretending to have an instrument present such as playing air guitar, such as to avoid noise or make recordings, or, for conducting of a virtual orchestra, ensemble, band, big band, choir, or the like, for practicing, exercising, recording or entertainment purposes or the like.

Further, in the context of safety and surveillance, devices according to the present invention in combination with gesture recognition may be used to recognize motion profiles of persons, such as recognizing a person by the way of walking or moving the body, or to use hand signs or movements or signs or movements of body parts or the whole body as access or identification control such as a personal identification sign or a personal identification movement.

Further, in the context of smart home applications or internet of things, devices according to the present invention in combination with gesture recognition may be used for central or non-central control of household devices which may be part of an interconnecting network of home appliances and/or household devices, such as refrigerators, central heating, air condition, microwave ovens, ice cube makers, or water boilers, or entertainment devices, such as television sets, smart phones, game consoles, video recorders, DVD players, personal computers, laptops, tablets, or combinations thereof, or a combination of household devices and entertainment devices.

Further, in the context of virtual reality or of augmented reality, devices according to the present invention in combination with gesture recognition may be used to control movements or function

of the virtual reality application or of the augmented reality application, such as playing or controlling a game using signs, gestures, body movements or body part movements or the like, moving through a virtual world, manipulating virtual objects, practicing, exercising or playing sports, arts, crafts, music or games using virtual objects such as a ball, chess figures, go stones, instruments, tools, brushes.

Further, in the context of medicine, devices according to the present invention in combination with gesture recognition may be used to support rehabilitation training, remote diagnostics, or to monitor or survey surgery or treatment, to overlay and display medical images with positions of medical devices, or to overlay display prerecorded medical images such as from magnetic resonance tomography or x-ray or the like with images from endoscopes or ultra sound or the like that are recorded during an surgery or treatment.

Further, in the context of manufacturing and process automation, devices according to the present invention in combination with gesture recognition may be used to control, teach, or program robots, drones, unmanned autonomous vehicles, service robots, movable objects, or the like, such as for programming, controlling, manufacturing, manipulating, repairing, or teaching purposes, or for remote manipulating of objects or areas, such as for safety reasons, or for maintenance purposes.

Further, in the context of business intelligence metrics, devices according to the present invention in combination with gesture recognition may be used for people counting, surveying customer movements, areas where customers spend time, objects, customers test, take, probe, or the like.

Further, devices according to the present invention may be used in the context of do-it-yourself or professional tools, especially electric or motor driven tools or power tools, such as drilling machines, saws, chisels, hammers, wrenches, staple guns, disc cutters, metals shears and nibblers, angle grinders, die grinders, drills, hammer drills, heat guns, wrenches, sanders, engraivers, nailers, jig saws, buiscuit joiners, wood routers, planers, polishers, tile cutters, washers, rollers, wall chasers, lathes, impact drivers, jointers, paint rollers, spray guns, morticers, or welders, in particular, to support precision in manufacturing, keeping a minimum or maximum distance, or for safety measures.

Further, the devices according to the present invention may be used to aid visually impaired persons. Further, devices according to the present invention may be used in touch screen such as to avoid direct context such as for hygienic reasons, which may be used in retail environments, in medical applications, in production environments, or the like. Further, devices according to the present invention may be used in agricultural production environments such as in stable cleaning robots, egg collecting machines, milking machines, harvesting machines, farm machinery, harvesters, forwarders, combine harvesters, tractors, cultivators, ploughs, destoners, harrows, strip tills, broadcast seeders, planters such as potato planters, manure spreaders, sprayers, sprinkler systems, swathers, balers, loaders, forklifts, mowers, or the like.

Further, devices according to the present invention may be used for selection and/or adaption of clothing, shoes, glasses, hats, prosthesis, dental braces, for persons or animals with limited communication skills or possibilities, such as children or impaired persons, or the like. Further, devices according to the present invention may be used in the context of warehouses, logistics, distribution, shipping, loading, unloading, smart manufacturing, industry 4.0, or the like. Further, in a manufacturing context, devices according to the present invention may be used in the context of processing, dispensing, bending, material handling, or the like.

The evaluation device may be or may comprise one or more integrated circuits, such as one or more application-specific integrated circuits (ASICs), and/or one or more data processing devices, such as one or more computers, preferably one or more microcomputers and/or microcontrollers, Field Programmable Arrays, or Digital Signal Processors. Additional components may be comprised, such as one or more preprocessing devices and/or data acquisition devices, such as one or more devices for receiving and/or preprocessing of the sensor signals, such as one or more AD-converters and/or one or more filters. Further, the evaluation device may comprise one or more measurement devices, such as one or more measurement devices for measuring electrical currents and/or electrical voltages. Further, the evaluation device may comprise one or more data storage devices. Further, the evaluation device may comprise one or more interfaces, such as one or more wireless interfaces and/or one or more wire-bound interfaces.

The at least one evaluation device may be adapted to perform at least one computer program, such as at least one computer program adapted for performing or supporting one or more or even all of the method steps of the method according to the present invention. As an example, one or more algorithms may be implemented which, by using the sensor signals as input variables, may determine the position of the object.

The evaluation device can be connected to or may comprise at least one further data processing device that may be used for one or more of displaying, visualizing, analyzing, distributing, communicating or further processing of information, such as information obtained by the optical sensor and/or by the evaluation device. The data processing device, as an example, may be connected or incorporate at least one of a display, a projector, a monitor, an LCD, a TFT, a loudspeaker, a multichannel sound system, an LED pattern, or a further visualization device. It may further be connected or incorporate at least one of a communication device or communication interface, a connector or a port, capable of sending encrypted or unencrypted information using one or more of email, text messages, telephone, Bluetooth, Wi-Fi, infrared or internet interfaces, ports or connections. It may further be connected or incorporate at least one of a processor, a graphics processor, a CPU, an Open Multimedia Applications Platform (OMAP™), an integrated circuit, a system on a chip such as products from the Apple A series or the Samsung S3C2 series, a microcontroller or microprocessor, one or more memory blocks such as ROM, RAM, EEPROM, or flash memory, timing sources such as oscillators or phase-locked loops, counter-timers, real-time timers, or power-on reset generators, voltage regulators, power management circuits, or DMA controllers. Individual units may further be connected by

buses such as AMBA buses or be integrated in an Internet of Things or Industry 4.0 type network.

The evaluation device and/or the data processing device may be connected by or have further external interfaces or ports such as one or more of serial or parallel interfaces or ports, USB, Centronics Port, FireWire, HDMI, Ethernet, Bluetooth, RFID, Wi-Fi, USART, or SPI, or analogue interfaces or ports such as one or more of ADCs or DACs, or standardized interfaces or ports to further devices such as a 2D-camera device using an RGB-interface such as CameraLink. The evaluation device and/or the data processing device may further be connected by one or more of interprocessor interfaces or ports, FPGA-FPGA-interfaces, or serial or parallel interfaces ports. The evaluation device and the data processing device may further be connected to one or more of an optical disc drive, a CD-RW drive, a DVD+RW drive, a flash drive, a memory card, a disk drive, a hard disk drive, a solid state disk or a solid state hard disk.

The evaluation device and/or the data processing device may be connected by or have one or more further external connectors such as one or more of phone connectors, RCA connectors, VGA connectors, hermaphrodite connectors, USB connectors, HDMI connectors, 8P8C connectors, BCN connectors, IEC 60320 C14 connectors, optical fiber connectors, D-subminiature connectors, RF connectors, coaxial connectors, SCART connectors, XLR connectors, and/or may incorporate at least one suitable socket for one or more of these connectors.

Possible embodiments of a single device incorporating one or more of the detectors according to the present invention, the evaluation device or the data processing device, such as incorporating one or more of the optical sensor, optical systems, evaluation device, communication device, data processing device, interfaces, system on a chip, display devices, or further electronic devices, are: mobile phones, personal computers, tablet PCs, televisions, game consoles or further entertainment devices. In a further embodiment, the 3D-camera functionality which will be outlined in further detail below may be integrated in devices that are available with conventional 2D-digital cameras, without a noticeable difference in the housing or appearance of the device, where the noticeable difference for the user may only be the functionality of obtaining and or processing 3D information. Further, devices according to the present invention may be used in 360° digital cameras or surround view cameras.

Specifically, an embodiment incorporating the detector and/or a part thereof such as the evaluation device and/or the data processing device may be: a mobile phone incorporating a display device, a data processing device, the optical sensor, optionally the sensor optics, and the evaluation device, for the functionality of a 3D camera. The detector according to the present invention specifically may be suitable for integration in entertainment devices and/or communication devices such as a mobile phone.

A further embodiment of the present invention may be an incorporation of the detector or a part thereof such as the evaluation device and/or the data processing device in a device for use in automotive, for use in autonomous driving or for use in car safety systems such as Daimler's

Intelligent Drive system, wherein, as an example, a device incorporating one or more of the optical sensors, optionally one or more optical systems, the evaluation device, optionally a communication device, optionally a data processing device, optionally one or more interfaces, optionally a system on a chip, optionally one or more display devices, or optionally further electronic devices may be part of a vehicle, a car, a truck, a train, a bicycle, an airplane, a ship, a motorcycle. In automotive applications, the integration of the device into the automotive design may necessitate the integration of the optical sensor, optionally optics, or device at minimal visibility from the exterior or interior. The detector or a part thereof such as the evaluation device and/or the data processing device may be especially suitable for such integration into automotive design.

The detector according to the present invention may further be combined with one or more other types of sensors or detectors. Thus, the detector may further comprise at least one additional detector. The at least one additional detector may be adapted for detecting at least one parameter, such as at least one of: a parameter of a surrounding environment, such as a temperature and/or a brightness of a surrounding environment; a parameter regarding a position and/or orientation of the detector; a parameter specifying a state of the object to be detected, such as a position of the object, e.g. an absolute position of the object and/or an orientation of the object in space. Thus, generally, the principles of the present invention may be combined with other measurement principles in order to gain additional information and/or in order to verify measurement results or reduce measurement errors or noise.

As outlined above, the human-machine interface may comprise a plurality of beacon devices which are adapted to be at least one of directly or indirectly attached to the user and held by the user. Thus, the beacon devices each may independently be attached to the user by any suitable means, such as by an appropriate fixing device. Additionally or alternatively, the user may hold and/or carry the at least one beacon device or one or more of the beacon devices in his or her hands and/or by wearing the at least one beacon device and/or a garment containing the beacon device on a body part.

The beacon device generally may be an arbitrary device which may be detected by the at least one detector and/or which facilitates detection by the at least one detector. The beacon device may fully or partially be designed as a passive beacon device, such as by providing one or more reflective elements adapted to reflect a light beam generated by a separate illumination source. The at least one beacon device may permanently or temporarily be attached to the user in a direct or indirect way and/or may be carried or held by the user. The attachment may take place by using one or more attachment means and/or by the user himself or herself, such as by the user holding the at least one beacon device by hand and/or by the user wearing the beacon device.

Additionally or alternatively, the beacon devices may be at least one of attached to an object and integrated into an object held by the user, which, in the sense of the present invention, shall be included into the meaning of the option of the user holding the beacon devices. Thus, as will

be outlined in further detail below, the beacon devices may be attached to or integrated into a control element which may be part of the human-machine interface and which may be held or carried by the user, and of which the orientation may be recognized by the detector device. Thus, generally, the present invention also refers to a detector system comprising at least one detector device according to the present invention and which, further, may comprise at least one object, wherein the beacon devices are one of attached to the object, held by the object and integrated into the object. As an example, the object preferably may form a control element, the orientation of which may be recognized by a user. Thus, the detector system may be part of the human-machine interface as outlined above or as outlined in further detail below. As an example, the user may handle the control element in a specific way in order to transmit one or more items of information to a machine, such as in order to transmit one or more commands to the machine.

Alternatively, the detector system may be used in other ways. Thus, as an example, the object of the detector system may be different from a user or a body part of the user and, as an example, may be an object which moves independently from the user. As an example, the detector system may be used for controlling apparatuses and/or industrial processes, such as manufacturing processes and/or robotics processes. Thus, as an example, the object may be a machine and/or a machine part, such as a robot arm, the orientation of which may be detected by using the detector system.

The human-machine interface may be adapted in such a way that the detector device generates at least one item of information on the position of the user or of at least one body part of the user. Specifically in case a manner of attachment of the at least one beacon device to the user is known, by evaluating the position of the at least one beacon device, at least one item of information on a position and/or an orientation of the user or of a body part of the user may be gained.

The beacon device preferably is one of a beacon device attachable to a body or a body part of the user and a beacon device which may be held by the user. The beacon device may comprise at least one reflector adapted to reflect light generated by an illumination source, thereby generating a reflected light beam to be transmitted to the detector.

The object, which may form part of the detector system, may generally have an arbitrary shape. Preferably, the object being part of the detector system, as outlined above, may be a control element which may be handled by a user, such as manually. As an example, the control element may be or may comprise at least one element selected from the group consisting of: a glove, a jacket, a hat, shoes, trousers and a suit, a stick that may be held by hand, a bat, a club, a racket, a cane, a toy, such as a toy gun. Thus, as an example, the detector system may be part of the human-machine interface and/or of the entertainment device.

As used herein, an entertainment device is a device which may serve the purpose of leisure and/or entertainment of one or more users, in the following also referred to as one or more

players. As an example, the entertainment device may serve the purpose of gaming, preferably computer gaming. Thus, the entertainment device may be implemented into a computer, a computer network or a computer system or may comprise a computer, a computer network or a computer system which runs one or more gaming software programs.

The entertainment device comprises at least one human-machine interface according to the present invention, such as according to one or more of the embodiments disclosed above and/or according to one or more of the embodiments disclosed below. The entertainment device is designed to enable at least one item of information to be input by a player by means of the human-machine interface. The at least one item of information may be transmitted to and/or may be used by a controller and/or a computer of the entertainment device. The at least one item of information preferably may comprise at least one command adapted for influencing the course of a game. Thus, as an example, the at least one item of information may include at least one item of information on at least one orientation of the player and/or of one or more body parts of the player, thereby allowing for the player to simulate a specific position and/or orientation and/or action required for gaming. As an example, one or more of the following movements may be simulated and communicated to a controller and/or a computer of the entertainment device: dancing; running; jumping; swinging of a racket; swinging of a bat; swinging of a club; pointing of an object towards another object, such as pointing of a toy gun towards a target.

The entertainment device as a part or as a whole, preferably a controller and/or a computer of the entertainment device, is designed to vary the entertainment function in accordance with the information. Thus, as outlined above, a course of a game might be influenced in accordance with the at least one item of information. Thus, the entertainment device might include one or more controllers which might be separate from the evaluation device of the at least one detector and/or which might be fully or partially identical to the at least one evaluation device or which might even include the at least one evaluation device. Preferably, the at least one controller might include one or more data processing devices, such as one or more computers and/or microcontrollers.

As further used herein, a tracking system is a device which is adapted to gather information on a series of past positions of the at least one object and/or at least one part of the object. Additionally, the tracking system may be adapted to provide information on at least one predicted future position and/or orientation of the at least one object or the at least one part of the object. The tracking system may have at least one track controller, which may fully or partially be embodied as an electronic device, preferably as at least one data processing device, more preferably as at least one computer or microcontroller. Again, the at least one track controller may fully or partially comprise the at least one evaluation device and/or may be part of the at least one evaluation device and/or may fully or partially be identical to the at least one evaluation device.

The tracking system comprises at least one detector according to the present invention, such as at least one detector as disclosed in one or more of the embodiments listed above and/or as

disclosed in one or more of the embodiments below. The tracking system further comprises at least one track controller. The track controller is adapted to track a series of positions of the object at specific points in time, such as by recording groups of data or data pairs, each group of data or data pair comprising at least one position information and at least one time information.

The tracking system may further comprise the at least one detector system according to the present invention. Thus, besides the at least one detector and the at least one evaluation device and the optional at least one beacon device, the tracking system may further comprise the object itself or a part of the object, such as at least one control element comprising the beacon devices or at least one beacon device, wherein the control element is directly or indirectly attachable to or integratable into the object to be tracked.

The tracking system may be adapted to initiate one or more actions of the tracking system itself and/or of one or more separate devices. For the latter purpose, the tracking system, preferably the track controller, may have one or more wireless and/or wire-bound interfaces and/or other types of control connections for initiating at least one action. Preferably, the at least one track controller may be adapted to initiate at least one action in accordance with at least one actual position of the object. As an example, the action may be selected from the group consisting of: a prediction of a future position of the object; pointing at least one device towards the object; pointing at least one device towards the detector; illuminating the object; illuminating the detector.

As an example of application of a tracking system, the tracking system may be used for continuously pointing at least one first object to at least one second object even though the first object and/or the second object might move. Potential examples, again, may be found in industrial applications, such as in robotics and/or for continuously working on an article even though the article is moving, such as during manufacturing in a manufacturing line or assembly line. Additionally or alternatively, the tracking system might be used for illumination purposes, such as for continuously illuminating the object by continuously pointing an illumination source to the object even though the object might be moving. Further applications might be found in communication systems, such as in order to continuously transmit information to a moving object by pointing a transmitter towards the moving object.

The proposed devices and methods provide a large number of advantages over known detectors of this kind. Thus, the detector generally may avoid the shortcomings of the known prior art systems disclosed above. Specifically, the detector may avoid the use of FiP sensors, thereby allowing for e.g. using simple and cheap and commercially available semiconductor sensors such as silicon photodiodes. These photodiodes generally do not show a luminance dependency, and the method disclosed above is generally independent from the brightness of the scenery and/or the brightness of the light spot on the light beam. Consequently, a range of measurement in terms of luminance or total power of the light beam entering the detector is generally larger in the present invention as compared to many of the devices disclosed above.

The detector according to the present invention may be realized as a simple device combining the functionality of distance measurement or measurement of z-coordinates, with the additional option of measuring one or more transversal coordinates, thereby integrating the functionality of a PSD.

Overall, in the context of the present invention, the following embodiments are regarded as preferred:

Embodiment 1: A detector for determining a position of at least one object, the detector comprising:

- at least one illumination source adapted to generate at least one illumination light beam for illuminating the object;
- a plurality of optical sensors, wherein each optical sensor has at least one light sensitive area, wherein at least one of the optical sensors is designed to generate at least one first sensor signal in response to an illumination of its respective light-sensitive area by a reflection light beam from the object, wherein the first sensor signal comprises at least one information about a first distance from the object to the light sensitive area of the optical sensor,
  wherein at least two of the optical sensors are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam, wherein each of the second sensor signals comprises at least one information about a beam profile of the reflection light beam impinging on the light sensitive area;
- at least one evaluation device, wherein the evaluation device is configured for determining at least one first longitudinal coordinate z_1 of the object by evaluating the first sensor signal, wherein the evaluation device is configured for determining at least one second longitudinal coordinate z_2 of the object by evaluating a first combined signal Q from the second sensor signals.

Embodiment 2: The detector according to the preceding embodiment, wherein the information about the first distance comprises at least one information of a time of flight the illumination light beam has traveled from the illumination source to the object and the reflection light beam has traveled from the object to the light sensitive area of the optical sensor.

Embodiment 3: The detector according to any one of the preceding embodiments, wherein each of the second sensor signals comprise at least one intensity information of the reflection light beam impinging on the light sensitive area.

Embodiment 4: The detector according to any one of the preceding embodiments, wherein each of the second sensor signals comprises at least one information about a second distance from the object to the light sensitive area of the optical sensor.

Embodiment 5: The detector according to any one of the preceding embodiments, wherein the detector is adapted to determine the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2 subsequently or simultaneously.

Embodiment 6: The detector according to any one of the preceding embodiments, wherein the detector is adapted to determine the first longitudinal coordinate and the second longitudinal coordinate independent from each other.

Embodiment 7: The detector according to any one of the preceding embodiments, wherein the evaluation device is adapted to use one of the first sensor signal and the second sensor signals to determine a longitudinal range and the other one of the first sensor signal and the second sensor signals to determine the longitudinal position within the longitudinal range.

Embodiment 8: The detector according to any one of the preceding embodiments, wherein all optical sensors are designed to generate the first sensor signal and the second sensor signal.

Embodiment 9: The detector according to any one of the preceding embodiments, wherein the detector comprises two optical sensors.

Embodiment 10: The detector according to the preceding embodiment, wherein a first optical sensor is designed to generate the first sensor signal and the second sensor signal and wherein a second optical sensor is designed to produce the second sensor signal.

Embodiment 11: The detector according to any one of the two preceding embodiments, wherein each of the optical sensors are designed to generate both the first sensor signal and second sensor signal.

Embodiment 12: The detector according to any one of the preceding embodiments, wherein the detector comprises two optical sensors, wherein the light sensitive areas of the optical sensors differ in size, wherein the light-sensitive area of the first optical sensor is smaller than the light-sensitive area of the second optical sensor.

Embodiment 13: The detector according to the preceding embodiment, wherein a gap is provided between the light sensitive-area of the first optical sensor and the light sensitive-area of second of the optical sensor.

Embodiment 14: The detector according to any one of the two preceding embodiments, wherein the detector comprises at least one slow measurement channel and at least one fast measurement channel, wherein the slow measurement channel comprises at least one of the first optical sensor and the second optical sensor and the fast measurement channel comprises the first optical sensor only.

Embodiment 15: The detector according to any one of the three preceding embodiments, wherein each of the first optical sensor and the second optical sensor is configured for generating the second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam, wherein each of the second sensor signals comprises the information about the beam profile of the reflection light beam impinging on the respective light sensitive area, wherein the evaluation device is configured for determining the second longitudinal coordinate z_2 of the object by evaluating the first combined signal Q from the second sensor signals.

Embodiment 16: The detector according to any one of the four preceding embodiments, wherein the first optical sensor is configured for generating the first sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam from the object, wherein the first sensor signal comprises the information about the first distance from the object to the light sensitive area of the optical sensor, wherein the information about the first distance comprises the information of the time of flight the illumination light beam has traveled from the illumination source to the object.

Embodiment 17: The detector according to any one of the five preceding embodiments, wherein the illumination source is arranged having an offset with respect to an optical axis of the detector.

Embodiment 18: The detector according to the preceding embodiment, wherein the illumination source and the light-sensitive areas of the first optical sensor and the second optical sensor are arranged such that in a far field only the first optical sensor is illuminated by the reflection light beam travelling from the object to the detector.

Embodiment 19: The detector according to any one of the two preceding embodiments, wherein the illumination source and the light-sensitive areas of the first optical sensor and the second optical sensor are arranged such that in a near field both of the light-sensitive areas of the first optical sensor and the second optical sensor are illuminated by the light beam travelling from the object to the detector.

Embodiment 20: The detector according to any one of the preceding embodiments, wherein the evaluation device is adapted to calibrate a determination of one of the first longitudinal coordinate z_1 by using the second longitudinal coordinate z_2 and/or to calibrate a determination of the second longitudinal coordinate z_2 by using the first longitudinal coordinate z_1.

Embodiment 21: The detector according to any one of the preceding embodiments, wherein the detector is adapted to be run in at least two modes, wherein in a first mode the detector is adapted to determine the first longitudinal coordinate z_1, wherein in a second mode the detector is adapted to determine the second longitudinal coordinate z_2.

Embodiment 22: The detector according to any one of the preceding embodiments, wherein the detector is adapted to be run in a combined mode, wherein both the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2 are determined.

Embodiment 23: The detector according to the preceding embodiment, wherein at least one of the optical sensors is adapted to generate at least one second combined signal, wherein the combined signal comprises the first sensor signal and one of the second sensor signals.

Embodiment 24: The detector according to the preceding embodiment, wherein the evaluation device is adapted to compare the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2.

Embodiment 25: The detector according to the preceding embodiment, wherein the evaluation device is adapted to perform at least one plausibility check, wherein the evaluation device is adapted to determine a difference of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2, wherein the evaluation device is adapted to determine if the difference is within at least one pre-determined and/or pre-defined limit.

Embodiment 26: The detector according to the preceding embodiment, wherein the evaluation device is adapted to one or more of discarding the first longitudinal coordinate z_1 and/or the second longitudinal coordinate z_2 and outputting at least one warning, for example at least one warning message and/or at least one audible signal, if the difference is above the pre-determined and/or pre-defined limit.

Embodiment 27: The detector according to any one of the preceding embodiments, wherein the evaluation device is adapted to determine a combined longitudinal coordinate z_{comb} by evaluating both the first sensor signal and the second sensor signals and/or by evaluating both the first sensor signal and the first combined signal and/or by evaluating the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2.

Embodiment 28: The detector according to the preceding embodiment, wherein the evaluation device is adapted to derive the combined longitudinal coordinate z_{comb} by determining a pulse period by using the second sensor signals and by determining a position within the determined period by using the first sensor signal.

Embodiment 29: The detector according to the preceding embodiment, wherein the evaluation device is adapted to derive the combined longitudinal coordinate z_{comb} by determining an average value of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2.

Embodiment 30: The detector according to any one of the preceding embodiments, wherein the evaluation device is adapted to determine at least one information about a signal quality.

Embodiment 31: The detector according to the preceding embodiment, wherein the evaluation device is adapted to select or discard dependent on the information about the signal quality at least one of the first sensor signal and/or the second sensor signals and to determine

- if the first sensor signal is selected, a longitudinal coordinate $z_{quality}$ of the object by evaluating the first sensor signal;
- if the second sensor signals are selected, the longitudinal coordinate $z_{quality}$ of the object by evaluating the first combined signal Q from the second sensor signals;
- if both the first sensor signal and the second sensor signals are selected, the longitudinal coordinate $z_{quality}$ of the object by evaluating both the first sensor signal and the second sensor signals and/or by evaluating both the first sensor signal and the first combined signal and/or by evaluating the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2.

Embodiment 32: The detector according to the preceding embodiment, wherein the evaluation device is adapted to determine whether the information about the signal quality is within at least one pre-defined limit.

Embodiment 33: The detector according to any one of the preceding embodiments, wherein the optical sensor adapted to generate the first sensor signal is designed as time-of-flight detector.

Embodiment 34: The detector according to the preceding embodiment, wherein the time-of-flight detector is selected from the group consisting of: at least one pulsed time-of-flight detector; at least one phase modulated time-of-flight detector; at least one direct time-of-flight detector; at least one indirect time-of-flight detector.

Embodiment 35: The detector according to any one of the preceding embodiments, wherein the illumination source comprises at least one light source selected from the group consisting of at least one laser source, in particular a pulsed laser source; at least one light emitting diode.

Embodiment 36: The detector according to any one of the preceding embodiments, wherein the illumination source is adapted to generate pulsed illumination.

Embodiment 37: The detector according to the preceding embodiments, wherein the evaluation device is adapted to determine in which pulse period the first sensor signal was generated.

Embodiment 38: The detector according to any one of the two preceding embodiments, wherein the detector is adapted to generate the second sensor signals over several pulse periods.

Embodiment 39: The detector according to any one of the three preceding embodiments, wherein the evaluation device comprises at least two memory elements, wherein the detector comprises at least two switches, wherein the switches are connected to the optical sensor adapted to generate the first sensor signal, wherein the switches are adapted to provide the first sensor signal to one of the memory elements.

Embodiment 40: The detector according to the preceding embodiment, wherein each of the switches is controlled by a control signal having a pulse length identical to a pulse length of a light pulse generated by the illumination source, wherein the control signal of one of the switches is delayed.

Embodiment 41: The detector according to the preceding embodiment, wherein the evaluation device is adapted to sample and/or store depending on the delay a first part of the first sensor signal through a first switch in a first memory element and the other, second part of the first sensor signal through a second switch in a second memory element.

Embodiment 42: The detector according to the preceding embodiment, wherein the evaluation device is adapted to determine the first longitudinal coordinate by evaluating the first part and second part of the first sensor signal.

Embodiment 43: The detector according to the preceding embodiment, wherein the evaluation device is adapted to determine the first longitudinal coordinate z_1 by

$$z_1 = \frac{1}{2} \cdot c \cdot t_0 \cdot \frac{S1_2}{S1_1 + S1_2} + z_0;$$

wherein c is the speed of light, t_0 is the pulse length of the illumination light beam, z_0 is a distance offset, and $S1_1$ and $S1_2$ are the first part and second part of the first sensor signal, respectively.

Embodiment 44: The detector according to any one of the preceding embodiments, wherein the evaluation device is configured for deriving the first combined signal Q by one or more of dividing the second sensor signals, dividing multiples of the second sensor signals, dividing linear combinations of the second sensor signals.

Embodiment 45: The detector according to the preceding embodiment, wherein the evaluation device is configured for using at least one predetermined relationship between the first combined signal Q and the second longitudinal coordinate z_2 for determining the second longitudinal coordinate z_2.

Embodiment 46: The detector according to any one of the preceding embodiments, wherein the evaluation device is configured for deriving the first combined signal Q by

$$Q(z_O) = \frac{\iint_{A_1} E(x,y;z_2)\,dxdy}{\iint_{A_2} E(x,y;z_2)\,dxdy}$$

wherein x and y are transversal coordinates, A1 and A2 are areas of a beam profile at the sensor position, and $E(x,y,z_2)$ denotes the beam profile given at the object distance z_2.

Embodiment 47: The detector according to any one of the preceding embodiments, wherein the detector comprises at least one transfer device, wherein the transfer device has at least one focal length in response to at least one incident light beam propagating from the object to the detector.

Embodiment 48: The detector according to the preceding embodiment, wherein the optical sensors are positioned off focus.

Embodiment 49: The detector according to any one of the two preceding embodiments, wherein the transfer device has an optical axis, wherein the transfer device constitutes a coordinate system, wherein a longitudinal coordinate l is a coordinate along the optical axis and wherein d is a spatial offset from the optical axis, wherein the optical sensors are arranged such that the light-sensitive areas of the optical sensors differ in at least one of: their longitudinal coordinate, their spatial offset, or their surface areas.

Embodiment 50: The detector according to any one of the preceding embodiments, wherein each of the second sensor signals comprises at least one information of at least one area of the beam profile of at least one beam profile of the reflection light beam.

Embodiment 51: The detector according to the preceding embodiment, wherein the beam profile is selected from the group consisting of a trapezoid beam profile; a triangle beam profile; a conical beam profile and a linear combination of Gaussian beam profiles.

Embodiment 52: The detector according to any one of the two preceding embodiments, wherein the light-sensitive areas are arranged such that one of the second sensor signals comprises information of a first area of the beam profile and the other one of the second sensor signals comprises information of a second area of the beam profile, wherein the first area of the beam profile and the second area of the beam profile are one or both of adjacent or overlapping regions.

Embodiment 53: The detector according to the preceding embodiment, wherein the evaluation device is configured to determine the first area of the beam profile and the second area of the beam profile.

Embodiment 54: The detector according to any one of the four preceding embodiments, wherein the first area of the beam profile comprises essentially edge information of the beam profile and the second area of the beam profile comprises essentially center information of the beam profile.

Embodiment 55: The detector according to any one of the two preceding embodiments, wherein the evaluation device is configured to derive the first combined signal Q by one or more of dividing the edge information and the center information, dividing multiples of the edge information

and the center information, dividing linear combinations of the edge information and the center information.

Embodiment 56: The detector according to any one of the preceding embodiments, wherein the detector has

- at least one sensor element having a matrix of optical sensors, the optical sensors each having a light-sensitive area, wherein each optical sensor is configured to generate the at least one second sensor signal in response to an illumination of the light-sensitive area by the at least one light beam propagating from the object to the detector;
- the at least one evaluation device configured for evaluating the second sensor signals, by
  a) determining at least one optical sensor having the highest second sensor signal and forming at least one center signal;
  b) evaluating the second sensor signals of the optical sensors of the matrix and forming at least one sum signal;
  c) determining at least one first combined signal by combining the center signal and the sum signal; and
  d) determining the at least one second longitudinal coordinate z_2 of the object by evaluating the first combined signal.

Embodiment 57: The detector according to the preceding embodiment, wherein the center signal is selected from the group consisting of: the highest sensor signal; an average of a group of sensor signals being within a predetermined range of tolerance from the highest sensor signal; an average of sensor signals from a group of optical sensors containing the optical sensor having the highest sensor signal and a predetermined group of neighboring optical sensors; a sum of sensor signals from a group of optical sensors containing the optical sensor having the highest sensor signal and a predetermined group of neighboring optical sensors; a sum of a group of sensor signals being within a predetermined range of tolerance from the highest sensor signal; an average of a group of sensor signals being above a predetermined threshold; a sum of a group of sensor signals being above a predetermined threshold; an integral of sensor signals from a group of optical sensors containing the optical sensor having the highest sensor signal and a predetermined group of neighboring optical sensors; an integral of a group of sensor signals being within a predetermined range of tolerance from the highest sensor signal; an integral of a group of sensor signals being above a predetermined threshold.

Embodiment 58: The detector according to any one of the two preceding embodiments, wherein the sum signal is selected from the group consisting of: an average over all sensor signals of the matrix; a sum of all sensor signals of the matrix; an integral of all sensor signals of the matrix; an average over all sensor signals of the matrix except for sensor signals from those optical sensors contributing to the center signal; a sum of all sensor signals of the matrix except for sensor signals from those optical sensors contributing to the center signal; an integral of all sensor signals of the matrix except for sensor signals from those optical sensors contributing to

the center signal; a sum of sensor signals of optical sensors within a predetermined range from the optical sensor having the highest sensor signal; an integral of sensor signals of optical sensors within a predetermined range from the optical sensor having the highest sensor signal; a sum of sensor signals above a certain threshold of optical sensors being located within a predetermined range from the optical sensor having the highest sensor signal; an integral of sensor signals above a certain threshold of optical sensors being located within a predetermined range from the optical sensor having the highest sensor signal.

Embodiment 59: The detector according to any one of the three preceding embodiments, wherein the first combined signal Q is derived by one or more of: forming a quotient of the center signal and the sum signal or vice versa; forming a quotient of a multiple of the center signal and a multiple of the sum signal or vice versa; forming a quotient of a linear combination of the center signal and a linear combination of the sum signal or vice versa.

Embodiment 60: The detector according to any one of the preceding embodiments, wherein the evaluation device comprises at least one divider, wherein the divider is configured for deriving the first combined signal.

Embodiment 61: The detector according to any one of the five preceding embodiments, wherein the evaluation device is further configured for determining at least one transversal coordinate of the object by evaluating a transversal position of the at least one optical sensor having the highest sensor signal.

Embodiment 62: The detector according to any one of the preceding embodiments, wherein the optical sensors are partial diodes of a bi-cell diode or a quadrant diode.

Embodiment 63: The detector according to the preceding embodiment, wherein the optical sensors have a geometrical center being off-centered from the optical axis of the detector.

Embodiment 64: A detector system for determining a position of at least one object, the detector system comprising at least one detector according to any one of the preceding embodiments, the detector system further comprising at least one beacon device adapted to direct at least one light beam towards the detector, wherein the beacon device is at least one of attachable to the object, holdable by the object and integratable into the object.

Embodiment 65: A human-machine interface for exchanging at least one item of information between a user and a machine, wherein the human-machine interface comprises at least one detector system according to the preceding embodiment, wherein the at least one beacon device is adapted to be at least one of directly or indirectly attached to the user and held by the user, wherein the human-machine interface is designed to determine at least one position of the user by means of the detector system, wherein the human-machine interface is designed to assign to the position at least one item of information.

Embodiment 66: An entertainment device for carrying out at least one entertainment function, wherein the entertainment device comprises at least one human-machine interface according to the preceding embodiment, wherein the entertainment device is designed to enable at least one item of information to be input by a player by means of the human-machine interface, wherein the entertainment device is designed to vary the entertainment function in accordance with the information.

Embodiment 67: A tracking system for tracking a position of at least one movable object, the tracking system comprising at least one detector system according to any one of the preceding embodiments referring to a detector system, the tracking system further comprising at least one track controller, wherein the track controller is adapted to track a series of positions of the object at specific points in time.

Embodiment 68: A scanning system for determining a depth profile of a scenery, the scanning system comprising at least one detector according to any of the preceding embodiments referring to a detector, the scanning system further comprising at least one illumination source adapted to scan the scenery with at least one light beam.

Embodiment 69: A camera for imaging at least one object, the camera comprising at least one detector according to any one of the preceding embodiments referring to a detector.

Embodiment 70: A method for determining a position of at least one object by using at least one detector, the method comprising the following steps:

- illuminating the object with at least one illumination light beam;
- providing a plurality of optical sensors, each optical sensor having a light-sensitive area, wherein at least one of the optical sensors is configured to generate a first sensor signal in response to an illumination of its respective light-sensitive area by a reflection light beam from the object, wherein the first sensor signal comprises at least one information of a first distance from the object to the light sensitive area of the optical sensor, wherein at least two of the optical sensors are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam, wherein each of the second sensor signals comprises at least one information about a beam profile of the reflection light beam impinging on the light sensitive area;
- illuminating the light-sensitive area of the at least one optical sensor adapted to generate the first sensor signal with the reflection light beam, wherein, thereby, the light-sensitive area generates the at least one first sensor signal;
- illuminating each of the light-sensitive areas of the at least two optical sensors adapted to generate the second sensor signal, wherein, thereby, each of the light-sensitive areas generates at least one second sensor signal; and
- evaluating the first sensor signal, thereby, determining at least one first longitudinal coordinate z_1 of the object,

- evaluating the second sensor signals, thereby, determining at least one second longitudinal coordinate z_2, wherein the evaluating comprises deriving a first combined signal Q of the second sensor signals.

Embodiment 71: The method according to the preceding embodiment, wherein the deriving of the first combined signal Q comprises one or more of dividing the second sensor signals, dividing multiples of the second sensor signals, dividing linear combinations of the second sensor signals.

Embodiment 72: The method according to any one of the two preceding embodiments, wherein the information about the first distance comprises at least one information of a time of flight the illumination light beam has traveled from the illumination source to the object and the reflection light beam has traveled from the object to the light sensitive area of the optical sensor.

Embodiment 73: The method according to any one of the three preceding embodiments, wherein each of the second sensor signals comprise at least one intensity information of the reflection light beam impinging on the light sensitive area.

Embodiment 74: The method according to any one of the four preceding embodiments, wherein each of the second sensor signals comprises at least one information about a second distance from the object to the light sensitive area of the optical sensor.

Embodiment 75: A use of the detector according to any one of the preceding embodiments relating to a detector, for a purpose of use, selected from the group consisting of: a position measurement in traffic technology; an entertainment application; an optical data storage application; a security application; a surveillance application; a safety application; a human-machine interface application; a logistics application; a tracking application; a photography application; a machine vision application; a robotics application; a quality control application; a manufacturing application; a use in combination with optical data storage and readout.

Brief description of the figures

Further optional details and features of the invention are evident from the description of preferred exemplary embodiments which follows in conjunction with the dependent claims. In this context, the particular features may be implemented in an isolated fashion or in combination with other features. The invention is not restricted to the exemplary embodiments. The exemplary embodiments are shown schematically in the figures. Identical reference numerals in the individual figures refer to identical elements or elements with identical function, or elements which correspond to one another with regard to their functions.

Specifically, in the figures:

Figure 1 shows an embodiment of a detector according to the present invention;

Figure 2 shows a further exemplary embodiment of a detector according to the present invention, a detector system, a human-machine interface, an entertainment device, a tracking system, a scanning system and a camera;

Figures 3A and 3B show for two different experimental setups with a white paper object experimental results of measured first and second longitudinal coordinates as a function of a real longitudinal coordinate z_{real} of the object ;

Figure 4A and 4B show for the two experimental setups of Figures 3A and 3B deviation of the measured first and second longitudinal coordinates from the real longitudinal coordinate as a function of the real longitudinal coordinate z_{real};

Figure 5A and 5B show for two different experimental setups in a multiple reflections environment experimental results of measured first and second longitudinal coordinates as a function of the real longitudinal coordinate z_{real};

Figures 6A and 6B show for the two experimental setups of Figures 5A and 5B deviation of the measured first and second longitudinal coordinates as a function of the real longitudinal coordinate z_{real};

Figures 7A and 7B show a schematic example of determination of a combined longitudinal coordinate by using a second combined signal;

Figures 8A and 8B show a schematic representation of extension of the longitudinal range by using the second combined signal;

Figures 9A and 9B show a schematic representation of an example of a distance measurement with improved precision;

Figures 10A and 10B show a schematic representation of a further example of a distance measurement with improved precision;

Figure 11 shows signal intensities for a smaller light sensitive-area of a first optical sensor and a larger light-sensitive area of a second optical sensor;

Figure 12 shows a first combined signal determined by dividing a second sensor signal of the first optical sensor and the second sensor signal of the second optical sensor;

Figure 13 shows experimental results of phase difference of a time-of-flight measurement;

Figure 14 shows further experimental results of the first combined signal as a function of the real longitudinal coordinate z_{real}; and

Figure 15 shows the phase difference corrected by the second longitudinal coordinate as a function of the real longitudinal coordinate z_{real}.

Detailed description of the embodiments:

In Fig. 1, a schematic view of a first embodiment of a detector 110 for determining a position of at least one object 112 is depicted.

The detector 110 comprises at least one illumination source 114. The illumination source 114, as an example, may comprise an artificial illumination source, in particular at least one laser and/or laser source, in particular a pulsed laser source, and/or at least one incandescent lamp and/or at least one semiconductor light source, for example, at least one light-emitting diode, in particular a pulsed light-emitting diode, in particular an organic and/or inorganic light-emitting diode. Various types of lasers may be employed, such as semiconductor lasers. Additionally or alternatively, non-laser light sources may be used, such as LEDs and/or light bulbs.

The illumination source 114 may be adapted to generate pulsed illumination. The illumination source 114 may be adapted to generate at least one light pulse. The light pulse may have a pre-defined length or time duration, for example in the nanoseconds range. The illumination source 114 may be adapted to periodically generate the light pulse. The illumination source 114 may be adapted to generate a pulsed light beam 116. For example, the illumination source 114 may be adapted to generate a continuous illumination light beam and the detector 110 may comprise at least one interruption device adapted to interrupt the illumination, in particular periodically. The interruption device may comprise at least one shutter and/or a beam chopper or some other type of periodic beam interrupting device, for example comprising at least one interrupter blade or interrupter wheel, which preferably rotates at constant speed and which can thus periodically interrupt the illumination. By way of example, the at least one interruption device can also be wholly or partly integrated into the illumination source 114.

The pulsed light beam 116 may be adapted for illuminating the object 112. The pulsed light beam 116 may be fully or partially reflected by the object 112 and travels back towards the detector 110, thereby forming the reflection light beam 118. The illumination source 114, as an example, may comprise one or more diaphragms, such as an adjustable diaphragm, e.g. an adjustable iris diaphragm and/or a pin hole.

The detector 110 comprises a plurality of optical sensors 120. The optical sensors 120, as shown e.g. in Fig. 1, may be part of an array 135 of optical sensors 120. In the embodiment of Figure 1, the array 135 may be a quadrant photodiode, and the optical sensors 120 may be par-

tial diodes of the quadrant photodiode. Each optical sensor 116 has at least one light-sensitive area 121. In this embodiment the optical sensors 120 may be arranged such that the light-sensitive areas 121 differ in their longitudinal coordinate and/or their surface areas and/or their surface shapes.

At least one of the optical sensors 120 is designed to generate at least one first sensor signal in response to an illumination of its respective light-sensitive area 121 by the reflection light beam 118 from the object 112. The first sensor signal comprises at least one information of a time of flight the illumination light beam 116 has traveled from the illumination source 114 to the object 112 and the reflection light beam 118 has traveled from the object 112 to the light sensitive area 121 of the optical sensor 120.

The optical sensor 120 adapted to generate the first sensor signal may be designed as time-of-flight detector. The time-of-flight detector may be selected from the group consisting of: at least one pulsed time-of-flight detector; at least one phase modulated time-of-flight detector; at least one direct time-of-flight detector; at least one indirect time-of-flight detector. For example, the pulsed time-of-flight detector may be at least one range gated imager and/or at least one direct time-of-flight imager. For example the phase modulated time-of-flight detector may be at least one RF-modulated light source with at least one phase detector. The optical sensor 120 may be adapted to determine a time delay between emission of the illumination light beam 116 by the illumination source 114 and receipt of the reflection light beam 118. For example, the optical sensor 120 adapted to generate the first sensor signal may be designed as pulsed time-of-flight-detector. The optical sensor 120 may be adapted to store the first sensor signal dependent on a receiving time of the reflection light beam 118 in a plurality of time windows, in particular subsequent time windows. The optical sensor 120 may be adapted to store dependent on the receiving time of the reflection light beam 118 the generated first sensor signal in at least one first time window and/or in at least one second time window. The first and second time windows may be correlated with the opening and closure of the interruption device. Duration of first and second time windows may be pre-defined. For example, the first sensor signal may be stored in the first time window during opening of the interruption device, whereas during closure of the interruption device the first sensor signal may be stored in the second time window. Other durations of time windows are thinkable. The first and the second time window may comprise information about background, signal height and signal shift.

The object 112 may comprise at least one beacon device 122, from which the reflection light beam 118 propagates towards the optical sensors 120. The reflection light beam 118, as an example, may propagate along an optical axis 124 of the detector 110. Other embodiments, however, are feasible. The optical detector 110, further, comprises at least one transfer device 126, such as at least one lens or a lens system, specifically for beam shaping. The transfer device 126 has at least one focal length in response to the incident light beam 116 propagating from the object 112 to the detector 110. The transfer device 126 has an optical axis 127, wherein the transfer device 126 and the detector 110 preferably may have a common optical axis. The transfer device 126 constitutes a coordinate system. A direction parallel or anti-parallel to the

optical axis 124, 127 may be defined as a longitudinal direction, whereas directions perpendicular to the optical axis 124, 127 may be defined as transversal directions, wherein a longitudinal coordinate l is a coordinate along the optical axis 124, 127 and wherein d is a spatial offset from the optical axis 124, 127. Consequently, the reflection light beam 118 is focused, such as in one or more focal points, and a beam width of the reflection light beam 118 may depend on a longitudinal coordinate z of the object 112, such as on a distance between the detector 110 and the beacon device 122 and/or the object 112. The optical sensors 120 may be positioned off focus. For details of this beam width dependency on the longitudinal coordinate, reference may be made to one or more of the above-mentioned prior art documents, such as to one or more of WO 2012/110924 A1 and/or WO 2014/097181 A1.

The illumination light beam 116 may be parallel to the optical axis 124. Other embodiments, i.e. off-axis illumination and/or illumination at an angle, are feasible, too. In order to provide an on-axis illumination, as an example, one or more reflective elements may be used, such as one or more prisms and/or mirrors, such as dichroitic mirrors, such as movable mirrors or movable prisms. In order to avoid an on-axis illumination, the illumination source may be placed close to the transfer device 126 or even behind the transfer device 126.

At least two of the optical sensors 120 are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area 121 by the reflection light beam 118. The second sensor signal comprises at least one intensity information of the reflection light beam 118 impinging on the light sensitive area. One of the optical sensors 120 designed to generate at least one second sensor signal may generate a second sensor signal s_1, whereas the other one of the optical sensors 120 designed to generate at least one second sensor signal may generate a second sensor signal s_2. Preferably, the optical sensors 120 are linear optical sensors, i.e. the sensor signals s_1 and s_2 each are solely dependent on the total power of the reflection light beam 118 or of the portion of the reflection light beam 116 illuminating their respective light-sensitive areas 121, whereas these sensor signals s_1 and s_2 are independent from the actual size of the light spot of illumination. In other words, preferably, the optical sensors 120 do not exhibit the above-described FiP effect.

The detector 110 comprises at least one evaluation device 128, as symbolically shown in Fig. 1. The first sensor signal is provided to the evaluation device 128. The evaluation device is configured for determining at least one first longitudinal coordinate z_1 of the object by evaluating the first sensor signal.

The second sensor signals s_1 and s_2 are provided to the evaluation device 128. The evaluation device 128 is embodied to derive a first combined signal Q. The evaluation device 128 may be adapted for evaluating the at least two second sensor signals and for deriving the second longitudinal coordinate z_2 thereof. The first combined signal provides, at least over a measurement range, a unique function of the distance. As an example, the combined signal may be or may comprise at least one quotient signal. The first combined signal Q, for example, may be derived by dividing the second sensor signals s_1 and s_2 or multiples or linear combinations thereof, and

may be used for deriving at least one item of information on a second longitudinal coordinate z_2 of the object 112 and/or the beacon device 122, from which the reflection light beam 118 propagates towards the detector 110. The evaluation device 128 may have at least one divider 130 for forming the first combined signal Q, and, as an example, at least one position evaluation device 128, for deriving the second longitudinal coordinate z_2 from the first combined signal Q. The evaluation device 128 may have at least one further position evaluation device 134, for deriving the first longitudinal coordinate z_1 from the first sensor signal. It shall be noted that the evaluation device 128 may fully or partially be embodied in hardware and/or software. Thus, as an example, one or more of the components may be embodied by appropriate software components.

It shall further be noted that the embodiments shown in Fig. 1 simply provide an embodiment for determining the longitudinal coordinate z of the object 112. It is also feasible, however, to modify the setups to provide additional information on a transversal coordinate of the object 112 and/or of parts thereof. As an example, e.g. in between the transfer device 126 and the optical sensors 120, one or more parts of the reflection light beam 118 may be branched off, and may be guided to a position-sensitive device such as one or more CCD and/or CMOS pixelated sensors and/or quadrant detectors and/or other position sensitive devices, which, from a transversal position of a light spot generated thereon, may derive a transversal coordinate of the object 112 and/or of parts thereof. The transversal coordinate may be used to verify and/or enhance the quality of the distance information. For further details, as an example, reference may be made to one or more of the above-mentioned prior art documents which provide for potential solutions of transversal sensors.

In Fig. 1, a setup of the detector 110 is shown in which the illumination light beam 116 travels off-axis, i.e. one or both of at an angle other than 0° with the optical axis 124 or parallel to the optical axis 124 but shifted from the optical axis 124. This embodiment demonstrates that the method according to the present invention can be further enhanced by increasing the z-dependency of a combined signal. Thus, in Fig. 1, a side view is shown with two different positions of the object 112, i.e. a first position at z_A, drawn in solid lines, and a second position at z_B, drawn in dashed lines. As can be seen, the illumination light beam 116 which, as an example, propagates at an angle of 5° to 30°, e.g. 10° to 20°, with the optical axis 124, hits the object 112 in both cases at different positions. From these points of the object 112 illuminated by the illumination light beam 116, reflection light beams 118 propagate towards the detector 110, wherein, again, the reflection light beam 118 for the object 112 being located at position z_A is drawn in solid lines, wherein the reflection light beam 118 for the object 112 being located at position z_B is drawn in dashed lines. As can be seen in this setup, the position of a light spot 136 moves with the longitudinal position z of the object 112, for example with z_A and z_B. Thus, not only is the size of the light spot 136 affected by the longitudinal position z but also is the position on the array 134 of the light spot 136 changed. By this movement of the light spot 136, the z-dependency of the first combined signal taking into account at least two sensor signals of the optical sensors 120 may be increased.

As an example, the four diodes of the array 135 are denoted by D1-D4. In case of an on axis illumination and reflection, the first combined signal Q, as an example, may be formed as Q = i(D1)/i(D4), with i(D1) being the second sensor signal of photodiode D1, and i(D4) being the second sensor signal of photodiode D4. In case the spot size increases and the spot becomes more diffuse, i(D4) will increase more rapidly than i(D1), such that the quotient signal Q decreases. Contrarily, in case of an off axis illumination and reflection, both the size and the position of the light spot 136 are dependent on the z-coordinate. Thus, the tendency of the z-dependency of the combined signal such as the quotient signal Q will be increased. The position dependency of the light spot 136 can result in three different situations depending on the relative position of light source, optical axis, and sensor: Firstly, the position dependency of the light spot 136 may result in a further decrease of the at least one decreasing sensor signal depending on the z-coordinate, while, simultaneously, the position dependency of the light spot 136 may result in a further increase of the at least one decreasing sensor signal depending on the z-coordinate compared to an on axis illumination. Secondly, the position dependency of the light spot 136 may result in a reduced decrease or even increase of the at least one decreasing sensor signal depending on the z-coordinate, while, simultaneously, the position dependency of the light spot 136 may result in a reduced increase or even decrease of the at least one decreasing sensor signal depending on the z-coordinate compared to an on axis illumination. Thirdly, the position dependency of the light spot 136 may be as such that the z-dependence of the sensor signals is largely unchanged compared to an on axis illumination. However, according to the present invention, object distance is not determined from the position of the light spot 136 on a sensor as done in triangulation methods. Instead, movement of the light spot 136 on the array 135 may be used to enhance dynamic of the sensor signals and/or the resulting combined signal Q which may result in an enhanced dynamic of the z-dependency.

Additionally, as known from the prior art, the sensor signals i(D1), i(D2), i(D3), i(D4) may also be used for determining a transversal position x, y of the object 112. Further, the sensor signals may also be used for verifying the z-coordinate determined by the present invention.

Fig. 2 shows, in a highly schematic illustration, an exemplary embodiment of a detector 110, e.g. according to the embodiment shown in Fig. 1. The detector 110 specifically may be embodied as a camera 138 and/or may be part of a camera 138. The camera 138 may be made for imaging, specifically for 3D imaging, and may be made for acquiring standstill images and/or image sequences such as digital video clips. Other embodiments are feasible.

Fig. 2 further shows an embodiment of a detector system 140, which, besides the at least one detector 110, comprises one or more beacon devices 122, which, in this example, may be attached and/or integrated into an object 112, the position of which shall be detected by using the detector 110. Fig. 2 further shows an exemplary embodiment of a human-machine interface 142, which comprises the at least one detector system 140 and, further, an entertainment device 144, which comprises the human-machine interface 142. The figure further shows an embodiment of a tracking system 146 for tracking a position of the object 112, which comprises the

detector system 140. The components of the devices and systems shall be explained in further detail below.

Fig. 2 further shows an exemplary embodiment of a scanning system 148 for scanning a scenery comprising the object 112, such as for scanning the object 112 and/or for determining at least one position of the at least one object 112. The scanning system 148 comprises the at least one detector 110, and, further, optionally, the at least one illumination source 114 as well as, optionally, at least one further illumination source. The illumination source 114 may comprise at least one beam splitting element 149. The scanning system 148 may be designed to generate a profile of the scenery including the object 112 and/or a profile of the object 112, and/or may be designed to generate at least one item of information about the distance between the at least one dot and the scanning system 148, specifically the detector 110, by using the at least one detector 110.

As outlined above, an exemplary embodiment of the detector 110 which may be used in the setup of Fig. 2 is shown in Fig. 1. Thus, the detector 110, besides the optical sensors 120, comprises at least one evaluation device 128, having e.g. the at least one divider 130 and/or the at least one position evaluation device 132, as symbolically depicted in Fig. 2. The components of the evaluation device 128 may fully or partially be integrated into a distinct device and/or may fully or partially be integrated into other components of the detector 110. Besides the possibility of fully or partially combining two or more components, one or more of the optical sensors 120 and one or more of the components of the evaluation device 128 may be interconnected by one or more connectors 150 and/or by one or more interfaces, as symbolically depicted in Fig. 2. Further, the one or more connectors 150 may comprise one or more drivers and/or one or more devices for modifying or preprocessing sensor signals. Further, instead of using the at least one optional connector 150, the evaluation device 128 may fully or partially be integrated into one or both of the optical sensors 120 and/or into a housing 152 of the detector 110. Additionally or alternatively, the evaluation device 128 may fully or partially be designed as a separate device.

In this exemplary embodiment, the object 112, the position of which may be detected, may be designed as an article of sports equipment and/or may form a control element or a control device 154, the position of which may be manipulated by a user 156. As an example, the object 112 may be or may comprise a bat, a racket, a club or any other article of sports equipment and/or fake sports equipment. Other types of objects 112 are possible. Further, the user 156 himself or herself may be considered as the object 112, the position of which shall be detected.

As outlined above, the detector 110 comprises the at least two optical sensors 120. The optical sensors 120 may be located inside the housing 152. Further, the detector 110 may comprise the at least one transfer device 126, such as one or more optical systems, preferably comprising one or more lenses.

An opening 158 inside the housing 152, which, preferably, is located concentrically with regard to the optical axis 124 of the detector 110, preferably defines a direction of view 160 of the de-

tector 110. A coordinate system 162 may be defined, in which a direction parallel or anti-parallel to the optical axis 124 may be defined as a longitudinal direction, whereas directions perpendicular to the optical axis 124 may be defined as transversal directions. In the coordinate system 162, symbolically depicted in Fig. 2, a longitudinal direction is denoted by z, and transversal directions are denoted by x and y, respectively. Other types of coordinate systems 168 are feasible, such as non-Cartesian coordinate systems.

The detector 110 may comprise the optical sensors 120 as well as, optionally, further optical sensors. As outlined above, the detector 110 comprises a plurality of optical sensors 120, for example arranged in array 135. For example, the optical sensors 120 may be arranged in a matrix of optical sensors 120, for example a rectangular matrix having one or more rows and one or more columns. Thus, the optical sensors 120 may be located at the same longitudinal coordinate. For example, as shown in Fig. 1, the optical sensors 120 may be partial diodes of a quadrant photodiode or, as a further example, the optical sensors 120 may be partial diodes of a bi-cell diode. The optical sensors 120 may be arranged such that the light-sensitive areas 121 of the optical sensors differ in spatial offset and/or surface areas. Additionally or alternatively, the optical sensors 120 may be located in one and the same beam path, one behind the other. Alternatively, however, a branched beam path may be possible, with additional optical sensors in one or more additional beam paths, such as by branching off a beam path for at least one transversal detector or transversal sensor for determining transversal coordinates of the object 112 and/or of parts thereof.

One or more reflection light beams 118 are propagating from the object 112 and/or from one or more of the beacon devices 122, towards the detector 110. The detector 110 is configured for determining a position of the at least one object 112. For this purpose, as explained above in the context of Fig. 1, the evaluation device 128 is configured to evaluate first and/or second sensor signals provided by the optical sensors 120. The detector 110 is adapted to determine a position of the object 112, and the optical sensors 120 are adapted to detect the reflection light beam 118 propagating from the object 112 towards the detector 110, specifically from one or more of the beacon devices 122. As beacon devices 122 a reflective surface of the object 112 may be used, such as integrated reflected beacon devices 122 having at least one reflective surface such as a mirror, retro reflector, reflective film, or the like. The reflection light beam 118, directly and/or after being modified by the transfer device 126, such as being focused by one or more lenses, illuminates the light-sensitive areas 121 of the optical sensors 120. For details of the evaluation, reference may be made to Fig. 1 above.

As outlined above, the determination of the position of the object 112 and/or a part thereof by using the detector 110 may be used for providing a human-machine interface 142, in order to provide at least one item of information to a machine 164. In the embodiments schematically depicted in Fig. 2, the machine 164 may be a computer and/or may comprise a computer. Other embodiments are feasible. The evaluation device 128 may even be fully or partially integrated into the machine 164, such as into the computer.

As outlined above, Fig. 2 also depicts an example of a tracking system 146, configured for tracking the position of the at least one object 112 and/or of parts thereof. The tracking system 146 comprises the detector 110 and at least one track controller 166. The track controller 166 may be adapted to track a series of positions of the object 112 at specific points in time. The track controller 166 may be an independent device and/or may be fully or partially integrated into the machine 164, specifically the computer, as indicated in Fig. 2 and/or into the evaluation device 128.

Similarly, as outlined above, the human-machine interface 142 may form part of an entertainment device 144. The machine 164, specifically the computer, may also form part of the entertainment device 144. Thus, by means of the user 156 functioning as the object 112 and/or by means of the user 156 handling the control device 154 functioning as the object 112, the user 156 may input at least one item of information, such as at least one control command, into the computer, thereby varying the entertainment functions, such as controlling the course of a computer game.

Figures 3A and 3B show experimental results of measured longitudinal coordinates z_{meas} in mm as a function of a real longitudinal coordinate z_{real} in mm of the object 112. Figures 4A and 4B show corresponding deviations $D = z_{meas} - z_{real}$ in mm of the measured longitudinal coordinates z_{meas} from the real longitudinal coordinate as a function of the real longitudinal coordinate z_{real} in mm. In particular, Figures 3A, 3B and 4A, 4B show a comparison of measured first longitudinal coordinates, depicted as solid line, and second longitudinal coordinates, depicted as dotted line. In the experiment, as an illumination source 114, a Laser components laser light source having a wavelength of 850 nm, available under FP-D-850-0.5M-C-F was used. A diaphragm in front of the laser source was used to vary the spot size. As optical sensors 120 a Basler tof640-20gm time-of-flight camera was used. In the experiment, z_{real} was varied from 100 mm to 1000 mm in 10 mm steps. As object 112 a piece of white paper was used. The first longitudinal coordinate was determined by using a time-of-flight measurement with the Basler tof640-20gm time-of-flight camera. The second longitudinal coordinate was determined by evaluating intensity information of the Basler tof640-20gm time-of-flight camera. Intensity information of the Basler tof640-20gm time-of-flight camera generated in a first region of the Basler tof640-20gm time-of-flight camera were assigned as one second sensor signal and sensor signals of the Basler tof640-20gm time-of-flight camera generated in a second region of the Basler tof640-20gm time-of-flight camera were assigned as further second sensor signal.

In Figures 3A and 4A, the laser source was mounted above the Basler tof640-20gm time-of-flight camera. As first region a first half of the light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. As second region a second half of the light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. The first and second halves were selected having a dividing line parallel to movement of the light spot 136. For details of the evaluation of the second sensor signals, reference may be made to Fig. 1 above. As shown in Figure 3A, below 500 mm time-of-flight measurements are not possible because of minimum measurement distance of the device, possibly due to the minimum measurement time of the internal clock. Determination of the second longitudinal coordinate is, however, possible in this

near region with deviations from z_{real} between +15 to -10 mm as shown in Figure 4A. Good agreement of first longitudinal coordinate by time-of-flight measurement and determination of second longitudinal coordinate can be found from 500 mm to 700 mm, with similar sized deviations. Above 700 mm, determination of second longitudinal coordinate exhibits larger deviations. Improvement of determination of second longitudinal coordinate may be achieved by optimizing experimental setup, in particular optics and optical sensors, for measurement of intensity information.

In the experimental setup of Figures 3B and 4B, the laser was arranged directly on top of the Basler tof640-20gm time-of-flight camera. The laser was modulated with a rectangle modulation, having a frequency of 500 Hz, 5V amplitude, 2,5V offset and 10% duty cycle. Before determining the second longitudinal coordinate, a calibration measurement was performed. In particular, the first combined signal was determined for variable distances and was plotted as a function of variable distance. The measurement values were fitted by a fifth degree polynomial as calibration curve. The measured longitudinal coordinates z_{meas} are determined by using the fifth degree polynomial and the intensity depending sensor signals. In Figures 3B and 4B, as first region an inner circle of the light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. As second region the entire light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. The inner circle was selected to comprise a fraction of the light sensitive area smaller than the entire light sensitive are. For details of the evaluation of the second sensor signals, reference may be made to Fig. 1 above. As shown in Figure 3B, below 500 mm time-of-flight measurements are not possible because of minimum measurement distance of the device, possibly due to the minimum measurement time of the internal clock. Determination of the second longitudinal coordinate is, however, possible in this near region with deviations from z_{real} between +10 to -10 mm as shown in Figure 4B. In comparison to Figures 3A and 4A, the selection of first region as inner circle and second region as entire light sensitive area leads to more precise results. As in Figures 3A and 4A, good agreement of first longitudinal coordinate by time-of-flight measurement and determination of second longitudinal coordinate can be found from 500 mm to 700 mm, with similar sized deviations. Above 700 mm, determination of second longitudinal coordinate exhibits larger deviations in comparison to Figures 3A and 4A.

In Figures 5A to 6B, the experimental setup described with respect to Figures 3A to 4B was used, but as object 112 a multiple reflections environment was used, in particular a 50 mm x 50 mm plastic box having a depth of 60 mm. On a base of the box a white paper as target was arranged. Figure 5A and 5B show results of measured first and second longitudinal coordinates in mm as a function of the real longitudinal coordinate z_{real} in mm. Figures 6A and 6B show corresponding deviation D in mm of the measured first and second longitudinal coordinates as a function of the real longitudinal coordinate z_{real} in mm. The measured first longitudinal coordinates are depicted as solid line, and second longitudinal coordinates are depicted as dotted line. In addition, in Figures 5A and 5B as reference an ideal dependency is depicted as dashed line.

In Figures 5A and 6A, the laser source was mounted above the Basler tof640-20gm time-of-flight camera. As first region a first half of the light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. As second region a second half of the light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. The first and second halves were selected having a dividing line parallel to movement of the light spot 136. For details of the evaluation of the second sensor signals, reference may be made to Fig. 1 above. In Figures 5B and 6B, as first region an inner circle of the light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. As second region the entire light sensitive region of the Basler tof640-20gm time-of-flight camera was selected. The inner circle was selected to comprise a fraction of light sensitive area smaller than the entire light sensitive area. For details of the evaluation of the second sensor signals, reference may be made to Fig. 1 above. Figures 5A to 6B show that time-of-flight measurements are influenced by multi path reflections and resulting in about 30 mm too high measurement results. Determination of the second longitudinal coordinate shows no influence caused by multi path reflections.

Figures 7A and 7B show a schematic example of determination of a combined longitudinal coordinate by using a second combined signal. In Figure 7B the first sensor signal s_1 and in Figure 7A the first combined signal s_2 is shown over the real longitudinal coordinate z_{real}. The z_{real} coordinates may be the same for both graphs. The first combined signal may have a precision ε_2 which may have a lower precision than the first sensor signal s_1. Thus, the error bar, $2\varepsilon_2$, of a measured second longitudinal coordinate, $z_{2,m}$, may be larger than for a measured first longitudinal coordinate $z_{1,m}$. A first measurement range of the first sensor signal may be $z_{1,I}$. A second measurement range of the first combined signal may be $z_{2,I}$ which may be identical to the first measurement range. The first sensor signal is periodic within the measurement range, $z_{1,I}$, with a period length of $z_{1,p}$. Thus, the same first sensor signal will be obtained for the distance $z_{1,m}$ and a distance $z_{1,m}+nz_{1,p}$, where n is an integer and the distance $z_{1,m}+nz_{1,p}$ is within the measurement range $z_{1,I}$. The first combined signal may be unique within the whole measurement range. The precision of the determined longitudinal coordinate from the first combined signal may be lower than the precision of the determined longitudinal coordinate from the first sensor signal. However, the longitudinal coordinate obtained from the first combined signal may be unique, since the first combined signal may be a monotonous function of the distance within the whole measurement range. The evaluation device may be adapted to determine the combined longitudinal coordinate $z_{comb,m}$ by

- determining non-unique first longitudinal coordinates $z_{1,m}$ from the first sensor signal $s_{1,m}$;
- determining a unique longitudinal coordinate, z_2, from the first combined signal $s_{2,m}$ and
- determining the first longitudinal coordinate, z_1, which is within the interval $z_{2,m}\pm\varepsilon_2$.

Figures 8A and 8B show a schematic representation of extension of the longitudinal range by using the second combined signal. In Figure 8B, the first sensor signal s_1 and in Figure 8A the first combined signal s_2 are shown over the real longitudinal coordinate z_{real}. The z_{real} coordinate may be the same for both graphs. Both signals may be non-monotonous functions of the longitudinal coordinate z_{real}. Thus, the longitudinal coordinate cannot be uniquely determined from one of the signals alone. Usually, the longitudinal range may be restricted to distances where

the signals are unique functions of z_{real}. If both signals s_1 and s_2 are available, the longitudinal range does not need to be restricted, as long as each signal pair (s_1,s_2) corresponds to a unique distance and vice versa. In particular, if a unique signal pair (s_1,s_2) exists for each longitudinal coordinate and vice versa, the evaluation device may be adapted to determine the unique combined longitudinal coordinate by

(1) selecting at least one first selected signal such as the first sensor signal and/or the second sensor signals and determining non-unique first longitudinal coordinates;

(2) selecting a second selected signal such as the first combined signal Q and/or the other sensor signal, which was not selected in step (1), and determining non-unique second longitudinal coordinates;

(3) determining whether one of the non-unique first longitudinal coordinates and the non-unique second longitudinal coordinates match up to a predetermined tolerance threshold;

(4) setting a combined unique longitudinal coordinate to be a matching longitudinal coordinate.

In step (1) and step (2), signals may be selected in the given order or may be performed in a different order. For example, in step (1) the first sensor signal may be selected and in step (2) the first combined signal Q may be selected. In another example, in step (1) the second senor signals may be selected, the at least one first combined signal may be determined and the non-unique first longitudinal sensor signal may be determined therefrom. In step (2), the first sensor signal may be selected.

Additionally or alternatively to step (4), the evaluation device may be adapted to output an error signal in case no matching coordinates are found and/or to output an error signal in case more than one matching coordinates are found. Additionally or alternatively, the signal pairs and their corresponding longitudinal coordinates may be stored in a look-up table. Additionally or alternatively, the signal pairs and their corresponding longitudinal coordinates may be approximated or described by an analytical function which is evaluated to find the longitudinal coordinate corresponding to a given signal pair.

Figures 9A and 9B show a schematic representation of an example of a distance measurement with improved precision. Figure 9B shows the first sensor signal s_1 and Figure 9A shows the first combined signal s_2 over the real longitudinal coordinate z_{real}. The z_{real} coordinate may be the same for both graphs. Both signals may be monotonous functions of the longitudinal coordinate z_{real}. The first combined signal may have a lower precision than the first sensor signal for smaller z_{real}, and an even lower precision for higher z_{real}. The first sensor signal may have a high precision for all z_{real} if the second sensor signal intensity is equal or higher than a predetermined intensity of the second sensor signal $i_{2,a}$. However, the first sensor signal may have a reduced precision under certain conditions such as for low intensities of the second sensor signals and higher z_{real} as shown schematically for second sensor signal $i_{2,b}$. However, in other examples behavior of first combined signal and first combined signal may be different, in particular opposite to the described behavior.

The evaluation device may be adapted to determine the combined longitudinal coordinate z_{comb} by determining the second sensor signal intensity i_2 and,

- if the second sensor signal intensity i_2 is equal or higher than the predetermined threshold intensity $i_{2,a}$, the combined longitudinal coordinate is determined to be the first longitudinal coordinate;
- if the second sensor signal intensity i_2 is lower than the predetermined threshold intensity $i_{2,a}$ and the second longitudinal coordinate is lower than a predetermined or selected distance threshold z_{limit}, the combined longitudinal coordinate is determined to be the first longitudinal coordinate;
- if the second sensor signal intensity is lower than the predetermined threshold intensity $i_{2,a}$ and the second longitudinal coordinate is higher than the distance threshold z_{limit}, the combined longitudinal coordinate is determined to be the second longitudinal coordinate.

However, for determination of the combined longitudinal coordinate instead of using behavior of the second sensor signal intensity i_2 behavior of the first sensor signal may be used. For example, the evaluation device may be adapted to determine the combined longitudinal coordinate z_{comb}

- if the first sensor signal, in particular precision of the first sensor signal, is equal or higher than a predetermined threshold, the combined longitudinal coordinate is determined to be the first longitudinal coordinate;
- if the first sensor signal, in particular precision of the first sensor signal, is lower than the predetermined threshold and the first longitudinal coordinate is lower than a predetermined or selected distance threshold z_{limit}, the combined longitudinal coordinate is determined to be the second longitudinal coordinate;
- if the first sensor signal, in particular precision of the first sensor signal, is lower than the predetermined threshold and the first longitudinal coordinate is higher than the distance threshold z_{limit}, the combined longitudinal coordinate is determined to be the first longitudinal coordinate.

The detector may be adapted to determine a plurality of combined longitudinal coordinates. If more than two second sensor signals are available, more than one combined first sensor signal may be formed. The detector may be adapted to determine the at least one combined longitudinal coordinate with enhanced precision by using the plurality of combined longitudinal coordinates. Figures 10A and 10B show a schematic representation of a further example of a distance measurement with improved precision. Figure 10B shows the first sensor signal s_1 and Figure 10A shows the first combined signal s_2 over the real longitudinal coordinate z_{real}. The z_{real} coordinate may be the same for both graphs. Both signals may be monotonous functions of the longitudinal coordinate z_{real}. The first combined signal may have a lower precision than the first sensor signal for smaller z_{real}, and an even lower precision for higher z_{real}. If more than two second sensor signals are available, more than one combined first sensor signal may be formed. The different first combined signals are indicated by $s_{2,a/b}$, $s_{2,a/c}$, and $s_{2,d/c}$, and may be formed for example by dividing the second sensor signal a by the second sensor signal b. The first sensor signal may have a high precision for all z_{real}. However, the first sensor signal may have a reduced precision or may deliver wrong results in case of multi-path reflections, such as in envi-

ronments where the illumination light beam may return directly and indirectly to the detector such as by reflections on metallic or other highly reflective surfaces.

The evaluation device may be adapted to determine the combined longitudinal coordinate z_{comb} by

a) Determining the first longitudinal coordinate from the first sensor signal;
b) Determining the second longitudinal coordinate from one of the combined second sensor signals;
c) Determining a difference of the first and second longitudinal coordinates. If the difference is below a predetermined threshold value, the combined longitudinal coordinate is determined to be the first longitudinal coordinate. If the difference is equal or larger than a predetermined or selected threshold value, the combined longitudinal coordinate may be determined from the combined second sensor signals only. In particular a plurality of second longitudinal coordinates may be determined from each of the combined second sensor signals. The difference of the second longitudinal coordinates may be determined. If the difference between at least two of the second longitudinal coordinates is below a further predetermined or selected threshold value, the combined longitudinal coordinate is determined to be one of the two second longitudinal coordinates and/or an average of the two longitudinal coordinates. If the difference between at least two of the second longitudinal coordinates is equal or larger than the further predetermined or selected threshold value, an error signal is given, indicating a measurement with low confidence.

In other examples, more than one first sensor signal may be available such that more than one first longitudinal coordinate may be determined. In this case determination of the combined longitudinal coordinate z_{comb} may be performed as described above with appropriate exchanges of the first sensor signals and second sensor signals.

Figures 11 and 12 show experimental results obtained by the detector 110 comprising two optical sensors 120. The light sensitive areas 121 of the optical sensors 120 may differ in size. The light-sensitive area 121 of a first optical sensor may be smaller than the light-sensitive area of a second optical sensor. For example, the first optical sensor has a small light-sensitive area of 1.5 mm x 1.5 mm and the second optical sensor has a large light-sensitive area of 1.5 mm x 4.1 mm. The first optical sensor and the second optical sensor may be a photodiode having two light sensitive areas 121. The first optical sensor and the second optical sensor may be arranged asymmetrically. In the experimental setup for Figures 11 and 12, the first optical sensor and the second optical sensor may be asymmetric dual-elements of a PIN-photodiode available as Hamamatsu® S9345. A gap may be provided between the light sensitive-area 121 of the first optical sensor and the light sensitive-area 121 of second of the optical sensor. Specifically, the gap between the light sensitive-area 121 of the first optical sensor and the light sensitive-area 121 of the second optical sensor may be 20 µm in a direction perpendicular to the optical axis 124.

The detector 110 may comprise at least one slow measurement channel and at least one fast measurement channel. The slow measurement channel may comprise at least one of the first optical sensor and the second optical sensor and the fast measurement channel may comprise the first optical sensor only. As outlined above, the light-sensitive area 121 of the first optical sensor may be smaller than the light-sensitive area 121 of the second optical sensor. In general, sensors with small light-sensitive areas 121 have lower capacities and thus, can be read out faster than sensors with larger light-sensitive areas. Each of the first optical sensor and the second optical sensor may be configured for generating the second sensor signal in response to the illumination of its respective light-sensitive area 121 by the reflection light beam 118. Each of the second sensor signals may comprises the information about the beam profile of the reflection light beam 118 impinging on the respective light sensitive area 121. The evaluation device 128 may be configured for determining the second longitudinal coordinate z_2 of the object 112 by evaluating the first combined signal Q from the second sensor signals. The first optical sensor may be configured for generating the first sensor signal in response to the illumination of its respective light-sensitive area 121 by the reflection light beam 118. The first sensor signal may comprise the information about the first distance from the object to the light sensitive area of the optical sensor. The information about the first distance may comprise the information of the time of flight the illumination light beam has traveled from the illumination source to the object 112.

The illumination source 114 may be arranged having an offset with respect to the optical axis 124. The illumination source 114 and the light-sensitive areas 121 of the first optical sensor and the second optical sensor may be arranged such that in a far field only the first optical sensor is illuminated by the reflection light beam 118. The illumination source 114 and the light-sensitive areas 121 of the first optical sensor and the second optical sensor may be arranged such that in a near field both of the light-sensitive areas 121 of the first optical sensor and the second optical sensor are illuminated by the light beam travelling from the object to the detector.

In case the illumination source 114 is arranged with an offset with respect to the optical axis 124 such as an offset in an x direction, a center of the light spot on the light-sensitive areas 121 of the respective optical sensor 120 may shift perpendicular to the optical axis, for example in the x direction by Δx. The shift of the center may depend on the distance Δz between the optical sensors 120 and the object 112. The shift of the center per object distance, $\Delta x/\Delta z$, may be larger for the near field compared to the shift of the center per object 112 distance for the far field. Thus, for distance measurements in the near field a large light-sensitive area 121, such as the second optical sensor 230 and/or both optical sensors 120, may be advantageous such that the light spot is situated in a broad measurement range on the detector 110. For distance measurements in the far field a small detector may be suitable. For distance measurements using time-of-flight techniques a smaller detector may be advantageous since small detectors comprise lower capacities and thus, can be read out faster as larger detectors.

For Figures 11 and 12, the larger light-sensitive area 121 of Hamamatsu® S9345 photodiode may be used for generating at least one of the second sensor signals for determining the first

combined signal Q and may be, specifically, advantageous in the near field. For example, the first combined signal may be determined by dividing the second sensor signals generated by the first and second optical sensors. The optical detector 120 having the larger light-sensitive area 121 may be used only for determining the second longitudinal coordinate z2. The optical sensor 120 having the smaller light-sensitive area may be used for both time-of-flight measurement and determining the second longitudinal coordinate z2. Using the larger light-sensitive area 121 only for determining the second longitudinal coordinate z2 but not for time-of-flight measurement allows to design a slower and low-priced measurement channel compared to the fast measurement channel for both time-of-flight measurement and determining the second longitudinal coordinate z2 from the first combined signal. The optical sensors 120 and the illumination source 114 may be arranged such that in far field only the optical sensor 120 having the smaller light-sensitive area is illuminated and such that for far field the longitudinal coordinate of the object 112 can be determined from time-of-flight measurement only. Thus, in the near field the longitudinal coordinate of the object 112 can be determined from the first combined signal using the second sensor signals generated by the first and the second optical sensors; in the far field the longitudinal coordinate of the object can be determined from time-of-flight measurement only; and in an intermediate distance range both, the first longitudinal coordinate z1 determined from time-of-flight and the second longitudinal coordinate z2 determined from the first combined signal using the second sensor signals generated by the first and the second optical sensors may be obtained.

Figure 11 shows signal intensities S in nA for the smaller light sensitive-area (curve 168) and for the larger light-sensitive area (curve 170) of the Hamamatsu® S9345 photodiode as a function of the object distance z in mm. Figure 12 shows the first combined signal Q determined by dividing the second sensor signal of the first optical sensor having the smaller light sensitive-area and the second sensor signal of the second optical sensor the larger light sensitive-area as a function of the object distance z in mm.

Figure 13 shows experimental results for the phase difference $\Delta\varphi$ in arbitrary units of a time-of-flight measurement as a function of the real longitudinal coordinate z_{real}. For the experimental setup as illumination source 114 a 100 mW laser diode with a wavelength of 980 nm, generating 15 single pulses with a frequency of 16.667 MHz, with a pulse repetition frequency of 5 kHz and a periodicity of around 9 m was used. As optical sensors 120 an avalanche quadrant photodiode available under First Sensor QA40000-10 TO was used. Figure 14 shows for the identical experimental setup experimental results of the obtained first combined signal as a function of the real longitudinal coordinate z_{real}. Figure 15 shows the second combined signal as a function of the real longitudinal coordinate z_{real} whereas the obtained as the second combined signal was obtained by correcting the periodicity of the phase difference using the second longitudinal coordinate.

List of reference numbers

110	detector
112	object
114	illumination source
116	illumination light beam
118	reflection light beam
120	optical sensor
121	light-sensitive area
122	beacon device
124	optical axis
126	transfer device
127	optical axis
128	evaluation device
130	divider
132	position evaluation device
134	further position evaluation device
135	array
136	light spot
138	camera
140	detector system
142	human-machine interface
144	entertainment device
146	tracking system
148	scanning system
149	beam splitting element
150	connector
152	housing
154	control device
156	user
158	opening
160	direction of view
162	coordinate system
164	machine
166	track controller
168	curve
170	curve

Patent claims

1. A detector (110) for determining a position of at least one object (112), the detector (110) comprising:
   - at least one illumination source (114) adapted to generate at least one illumination light beam (116) for illuminating the object (112);
   - a plurality of optical sensors (120), wherein each optical sensor (120) has at least one light sensitive area (121), wherein at least one of the optical sensors (120) is designed to generate at least one first sensor signal in response to an illumination of its respective light-sensitive area (121) by a reflection light beam (118) from the object (112), wherein the first sensor signal comprises at least one information about a first distance from the object (112) to the light sensitive area (121) of the optical sensor (120),
     wherein at least two of the optical sensors (120) are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area (121) by the reflection light beam (118), wherein each of the second sensor signal comprises at least one information about a beam profile of the reflection light beam (118) impinging on the light sensitive area (121);
   - at least one evaluation device (128), wherein the evaluation device (128) is configured for determining at least one first longitudinal coordinate z_1 of the object (112) by evaluating the first sensor signal, wherein the evaluation device (128) is configured for determining at least one second longitudinal coordinate z_2 of the object (112) by evaluating a first combined signal Q from the second sensor signals.

2. The detector (110) according to the preceding claim, wherein the information about the first distance comprises at least one information of a time of flight the illumination light beam (116) has traveled from the illumination source (114) to the object (112) and the reflection light beam (118) has traveled from the object (112) to the light sensitive area (121) of the optical sensor (120).

3. The detector (110) according to any one of the preceding claims, wherein each of the second sensor signals comprise at least one intensity information of the reflection light beam (118) impinging on the light sensitive area (121).

4. The detector (110) according to the preceding claim, wherein the detector (110) is adapted to determine the first longitudinal coordinate and the second longitudinal coordinate independent from each other.

5. The detector (110) according to any one of the preceding claims, wherein the evaluation device (128) is adapted to use one of the first sensor signal and the second sensor signals to determine a longitudinal range and the other one of the first sensor signal and the second sensor signals to determine the longitudinal position within the longitudinal range.

6. The detector (110) according to any one of the preceding claims, wherein the detector (110) comprises two optical sensors (120), wherein the light sensitive areas (121) of the optical sensors (120) differ in size, wherein the light-sensitive area (121) of a first optical sensor (120) is smaller than the light-sensitive area of a second optical sensor (120).

7. The detector (110) according to the preceding claim, wherein the illumination source (114) is arranged having an offset with respect to an optical axis (124) of the detector (110), wherein the illumination source (114) and the light-sensitive areas (121) of the first optical sensor (120) and the second optical sensor (120) are arranged such that in a far field only the first optical sensor (120) is illuminated by the light beam travelling from the object (112) to the detector (110), and/or wherein the illumination source (114) and the light-sensitive areas (121) of the first optical sensor (120) and the second optical sensor (120) are arranged such that in a near field both of the light-sensitive areas (121) of the first optical sensor (120) and the second optical sensor (120) are illuminated by the reflection light beam (118) travelling from the object (112) to the detector (110).

8. The detector (110) according to any one of the preceding claims, wherein the evaluation device (128) is adapted to calibrate a determination of the first longitudinal coordinate z_1 by using the second longitudinal coordinate z_2 and/or to calibrate a determination of the second longitudinal coordinate z_2 by using the first longitudinal coordinate z_1.

9. The detector (110) according to any one of the preceding claims, wherein the detector (110) is adapted to be run in a combined mode, wherein both the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2 are determined, wherein at least one of the optical sensors (120) is adapted to generate at least one second combined signal, wherein the combined signal comprises the first sensor signal and one of the second sensor signals, wherein the evaluation device (128) is adapted to compare the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2, wherein the evaluation device (128) is adapted to perform at least one plausibility check, wherein the evaluation device (128) is adapted to determine a difference of the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2, wherein the evaluation device (128) is adapted to determine if the difference is within at least one pre-determined and/or pre-defined limit.

10. The detector (110) according to the preceding claim, wherein the evaluation device (128) is adapted to one or more of discarding the first longitudinal coordinate z_1 and/or the second longitudinal coordinate z_2 and outputting at least one warning, for example at least one warning message and/or at least one audible signal, if the difference is above the pre-determined and/or pre-defined limit.

11. The detector (110) according to any one of the preceding claims, wherein the evaluation device (128) is adapted to determine a combined longitudinal coordinate z_{comb} by evaluating both the first sensor signal and the second sensor signals and/or by evaluating both

the first sensor signal and the first combined signal and/or by evaluating the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2.

12. The detector (110) according to the preceding claim, wherein the evaluation device (128) is adapted to derive the combined longitudinal coordinate z_{comb} by determining a pulse period by using the second sensor signals and by determining a position within the determined period by using the first sensor signal.

13. The detector (110) according to any one of the preceding claims, wherein the evaluation device (128) is adapted to determine at least one information about a signal quality, wherein the evaluation device (128) is adapted to select or discard dependent on the information about the signal quality at least one of the first sensor signal and/or the second sensor signals and to determine
- if the first sensor signal is selected, a longitudinal coordinate $z_{quality}$ of the object (112) by evaluating the first sensor signal;
- if the second sensor signals are selected, the longitudinal coordinate $z_{quality}$ of the object (112) by evaluating the first combined signal Q from the second sensor signals;
- if both the first sensor signal and the second sensor signals are selected, the longitudinal coordinate $z_{quality}$ of the object (112) by evaluating both the first sensor signal and the second sensor signals and/or by evaluating both the first sensor signal and the first combined signal and/or by evaluating the first longitudinal coordinate z_1 and the second longitudinal coordinate z_2.

14. The detector (110) according to the preceding claim, wherein the evaluation device (128) is adapted to determine whether the information about the signal quality is within at least one pre-defined limit.

15. The detector (110) according to any one of the preceding claims, wherein the optical sensor (120) adapted to generate the first sensor signal is designed as time-of-flight detector, wherein the time-of-flight detector (110) is selected from the group consisting of: at least one pulsed time-of-flight detector; at least one phase modulated time-of-flight detector; at least one direct time-of-flight detector; at least one indirect time-of-flight detector.

16. The detector (110) according to any one of the preceding claims, wherein the illumination source (114) is adapted to generate pulsed illumination.

17. The detector (110) according to any one of the preceding claims, wherein the evaluation device (128) is configured for deriving the first combined signal Q by one or more of dividing the second sensor signals, dividing multiples of the second sensor signals, dividing linear combinations of the second sensor signals, wherein the evaluation device is configured for using at least one predetermined relationship between the first combined signal Q and the second longitudinal coordinate z_2 for determining the second longitudinal coordinate z_2.

18. The detector (110) according to any one of the preceding claims, wherein the detector (110) has
    - at least one sensor element having a matrix of optical sensors (120), the optical sensors (120) each having a light-sensitive area (121), wherein each optical sensor (120) is configured to generate the at least one second sensor signal in response to an illumination of the light-sensitive area (121) by the at least one light beam propagating from the object (112) to the detector (110);
    - the at least one evaluation device (128) configured for evaluating the second sensor signals, by
        a) determining at least one optical sensor (120) having the highest second sensor signal and forming at least one center signal;
        b) evaluating the second sensor signals of the optical sensors (120) of the matrix and forming at least one sum signal;
        c) determining at least one first combined signal by combining the center signal and the sum signal; and
        d) determining the at least one second longitudinal coordinate z_2 of the object (112) by evaluating the first combined signal.

19. The detector (110) according to any one of the preceding claims, wherein the optical sensors (120) are partial diodes of a quadrant diode or partial diodes of a bi-cell diode.

20. A detector system (140) for determining a position of at least one object, the detector system (140) comprising at least one detector (110) according to any one of the preceding claims, the detector system (140) further comprising at least one beacon device (122) adapted to direct at least one light beam towards the detector (110), wherein the beacon device (122) is at least one of attachable to the object (112), holdable by the object (112) and integratable into the object (112).

21. A human-machine interface (142) for exchanging at least one item of information between a user (156) and a machine (164), wherein the human-machine interface (142) comprises at least one detector system (140) according to the preceding claim, wherein the at least one beacon device (122) is adapted to be at least one of directly or indirectly attached to the user (156) and held by the user (156), wherein the human-machine interface (142) is designed to determine at least one position of the user by means of the detector system (140), wherein the human-machine interface (142) is designed to assign to the position at least one item of information.

22. An entertainment device (144) for carrying out at least one entertainment function, wherein the entertainment device (144) comprises at least one human-machine interface (142) according to the preceding claim, wherein the entertainment device (144) is designed to enable at least one item of information to be input by a player by means of the human-machine interface (142), wherein the entertainment device (144) is designed to vary the entertainment function in accordance with the information.

23. A tracking system (146) for tracking a position of at least one movable object, the tracking system comprising at least one detector system (140) according to any one of the preceding claims referring to a detector system (140), the tracking system (146) further comprising at least one track controller (166), wherein the track controller is adapted to track a series of positions of the object (112) at specific points in time.

24. A scanning system (148) for determining a depth profile of a scenery, the scanning system (148) comprising at least one detector (110) according to any of the preceding claims referring to a detector, the scanning system (148) further comprising at least one illumination source adapted to scan the scenery with at least one light beam.

25. A camera (138) for imaging at least one object (112), the camera (138) comprising at least one detector (110) according to any one of the preceding claims referring to a detector.

26. A method for determining a position of at least one object (112) by using at least one detector (110), the method comprising the following steps:
- illuminating the object (112) with at least one illumination light beam (116);
- providing a plurality of optical sensors (120), each optical sensor (120) having a light-sensitive area (121), wherein at least one of the optical sensors (120) is configured to generate a first sensor signal in response to an illumination of its respective light-sensitive area (121) by a reflection light beam (118) from the object (112), wherein the first sensor signal comprises at least one information of a first distance from the object (112) to the light sensitive area (121) of the optical sensor (120), wherein at least two of the optical sensors (120) are designed to generate at least one second sensor signal in response to the illumination of its respective light-sensitive area by the reflection light beam (118), wherein each of the second sensor signal comprises at least one information about a beam profile of the reflection light beam (118) impinging on the light sensitive area (121);
- illuminating the light-sensitive area (121) of the at least one optical sensor (120) adapted to generate the first sensor signal with the reflection light beam (118), wherein, thereby, the light-sensitive area (121) generates the at least one first sensor signal;
- illuminating each of the light-sensitive areas (121) of the at least two optical sensors (120) adapted to generate the second sensor signal, wherein, thereby, each of the light-sensitive areas (121) generates at least one second sensor signal; and
- evaluating the first sensor signal, thereby, determining at least one first longitudinal coordinate z_1 of the object,
- evaluating the second sensor signals, thereby, determining at least one second longitudinal coordinate z_2, wherein the evaluating comprises deriving a first combined signal Q of the second sensor signals.

27. A use of the detector (110) according to any one of the preceding claims relating to a detector, for a purpose of use, selected from the group consisting of: a position measure-

ment in traffic technology; an entertainment application; an optical data storage application; a security application; a surveillance application; a safety application; a human-machine interface application; a logistics application; a tracking application; a photography application; a machine vision application; a robotics application; a quality control application; a manufacturing application; a use in combination with optical data storage and readout.

FIG.1

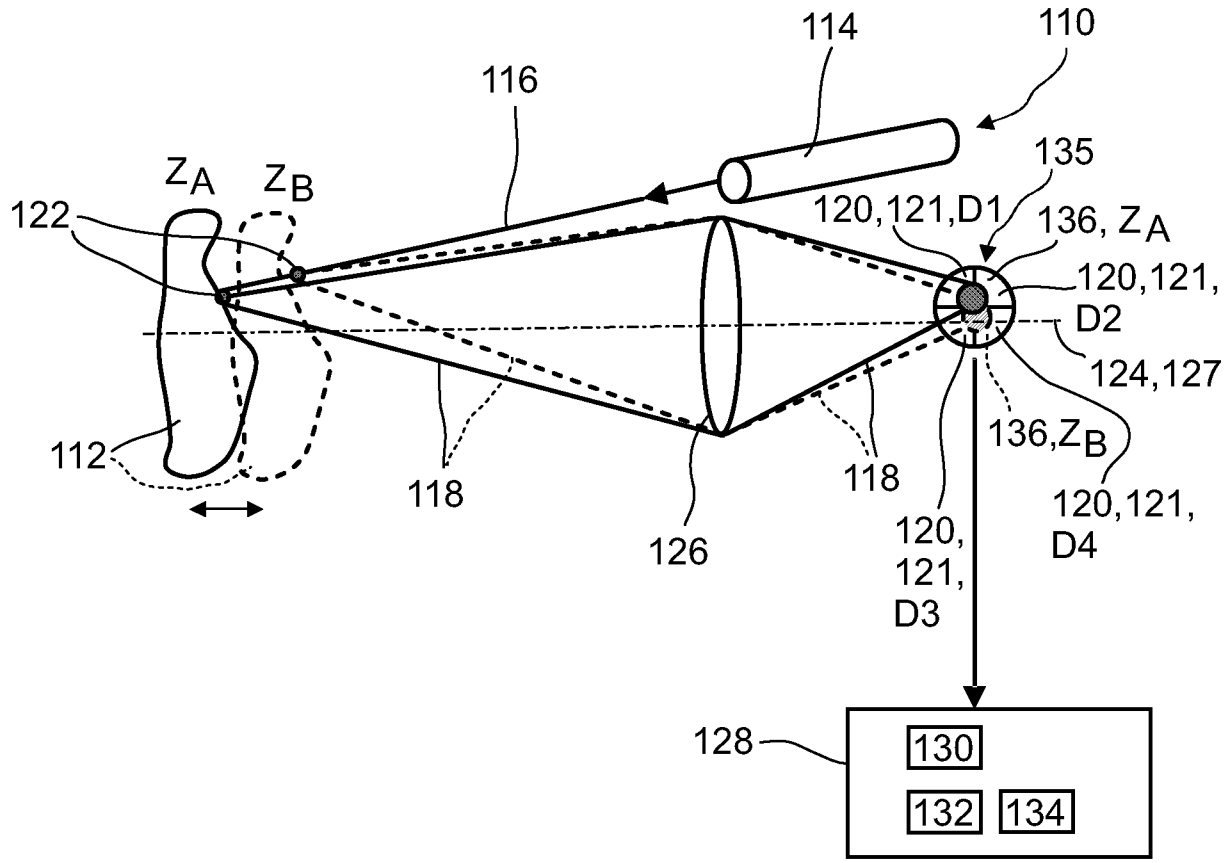

114
110
116
135
Z_A
Z_B
122
120,121,D1
136, Z_A
120,121,
D2
124,127
112
118
118
126
136,Z_B
120,121,
D4
120,
121,
D3
128
130
132
134

FIG.2

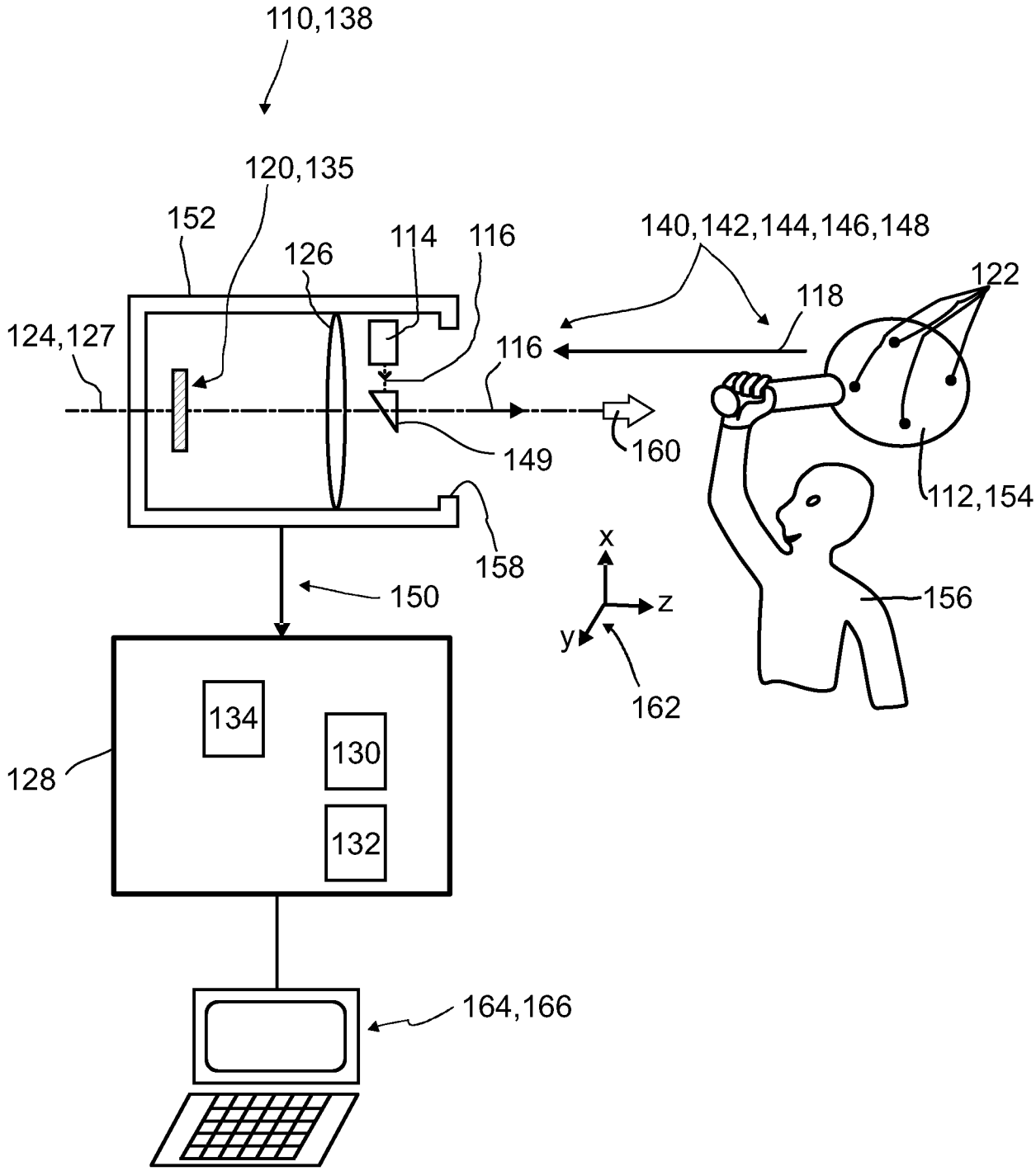

110,138
120,135
152
126
114
116
140,142,144,146,148
122
118
124,127
116
160
149
112,154
158
150
x
z
y
156
162
134
130
132
128
164,166

FIG.3A

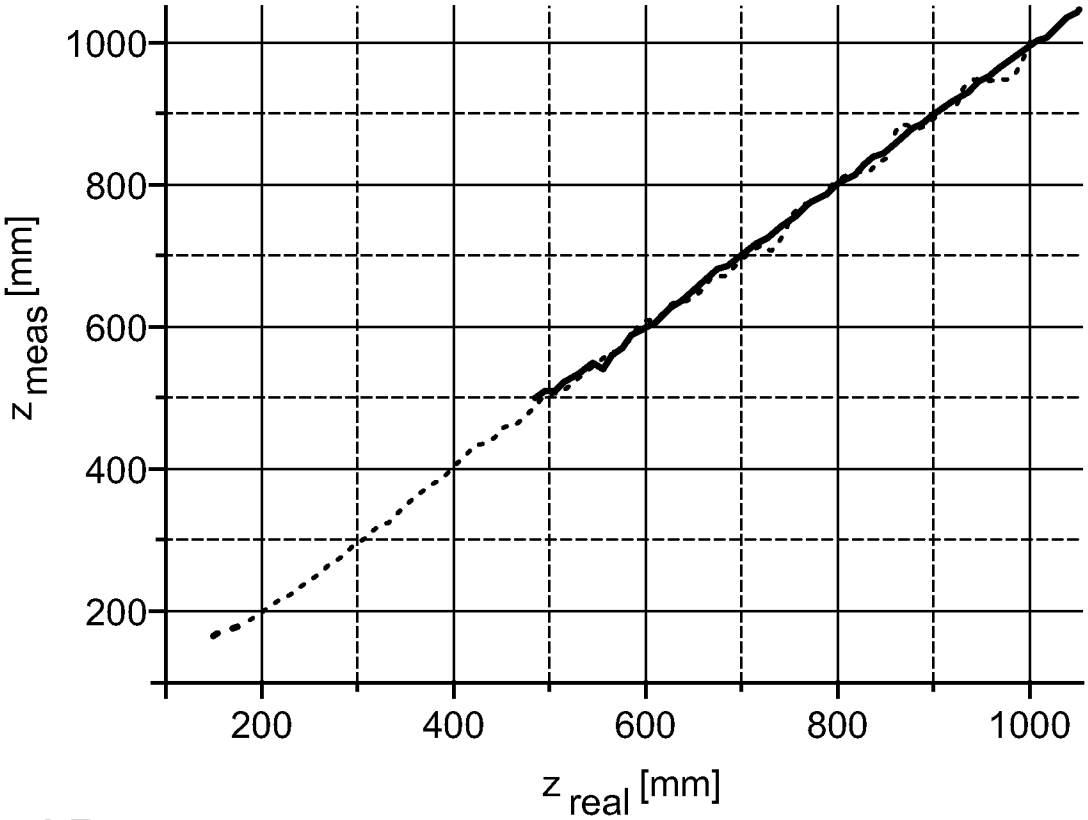

1000
800
600
400
200
z meas [mm]
200
400
600
800
1000
z real [mm]

FIG.3B

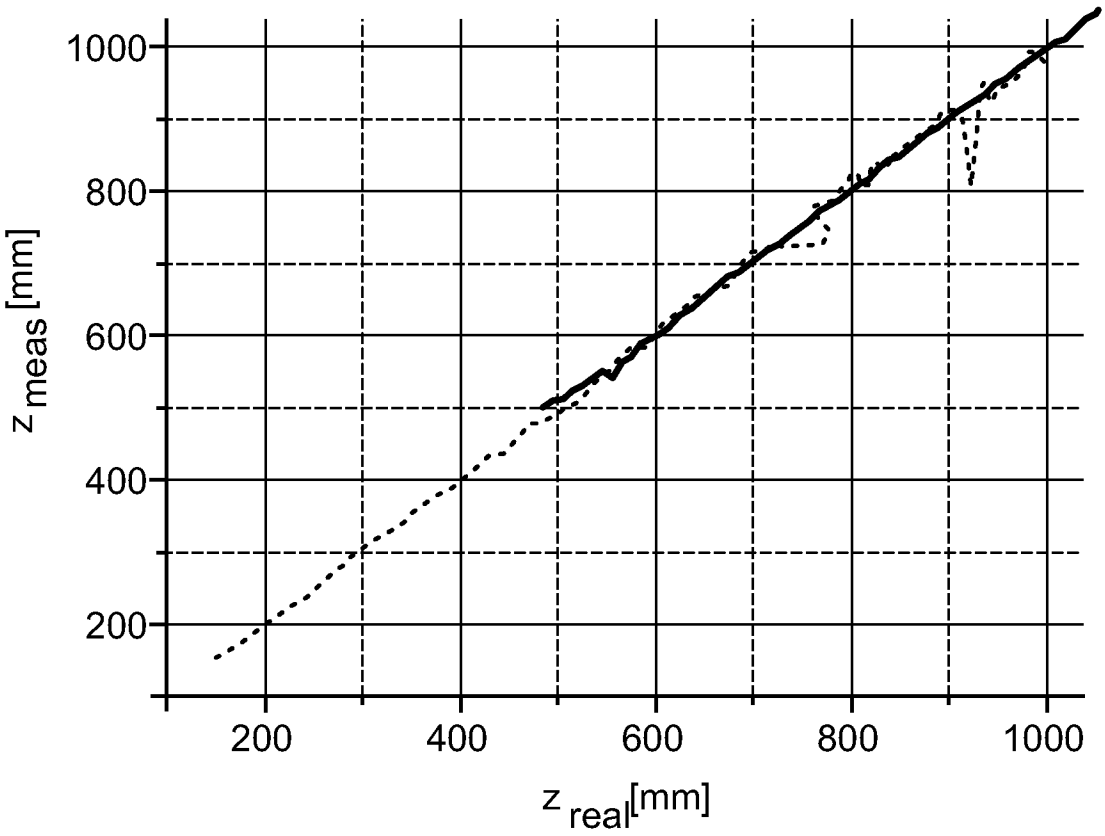

1000
800
600
400
200
z meas [mm]
200
400
600
800
1000
z real [mm]

FIG.4A

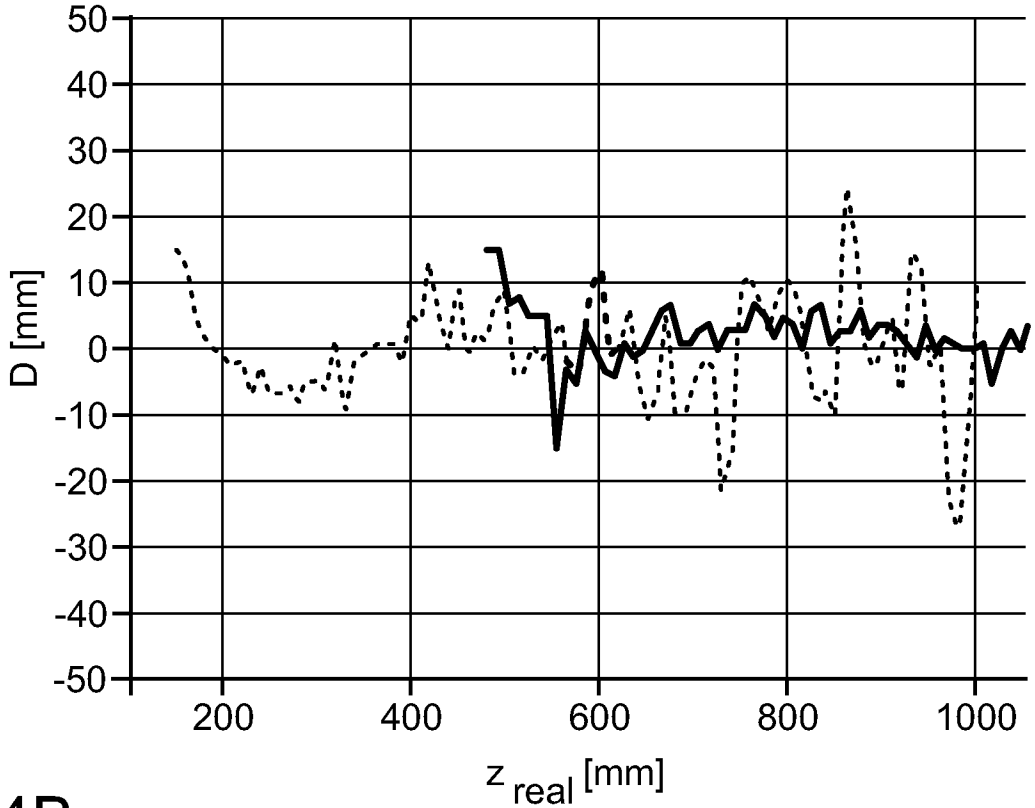

50
40
30
20
10
0
-10
-20
-30
-40
-50
D [mm]
200
400
600
800
1000
z real [mm]

FIG.4B

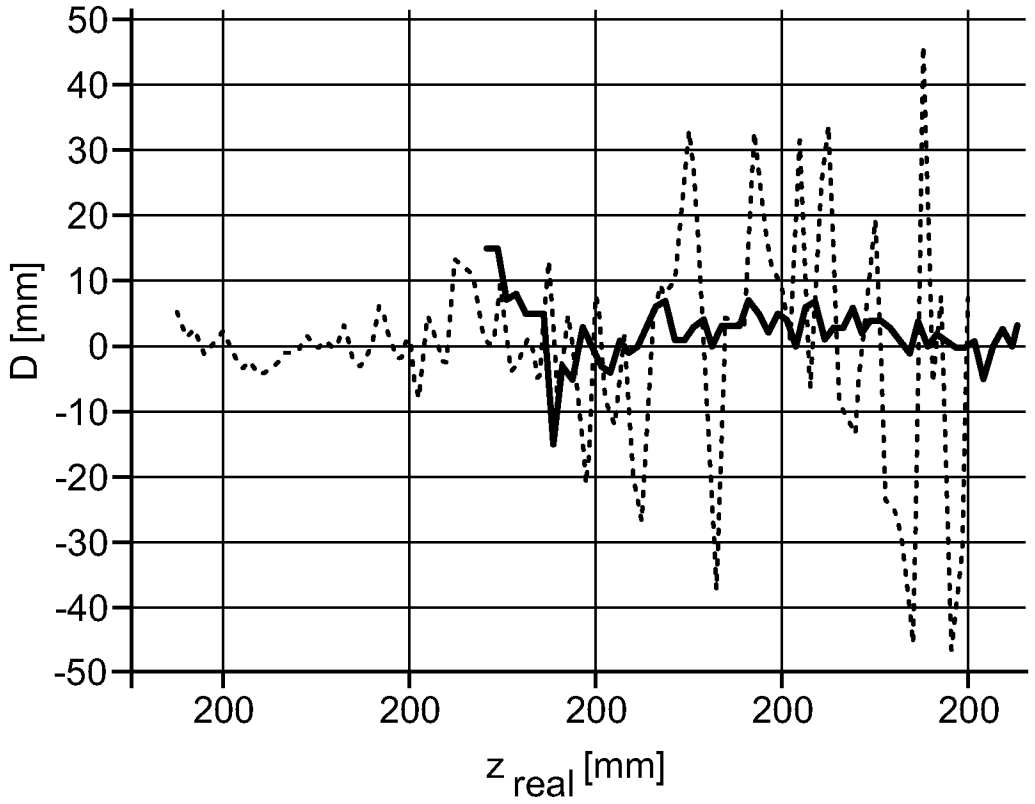

50
40
30
20
10
0
-10
-20
-30
-40
-50
D [mm]
200
200
200
200
200
z real [mm]

FIG.5A

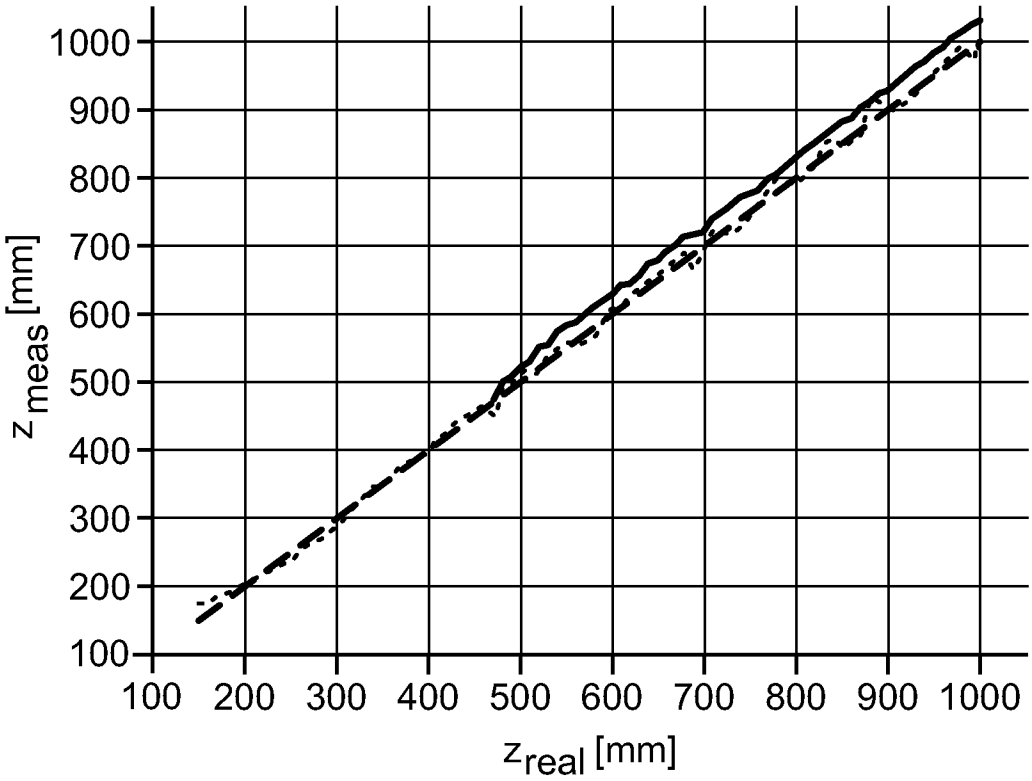

1000
900
800
700
600
500
400
300
200
100
z meas [mm]
100 200 300 400 500 600 700 800 900 1000
z real [mm]

FIG.5B

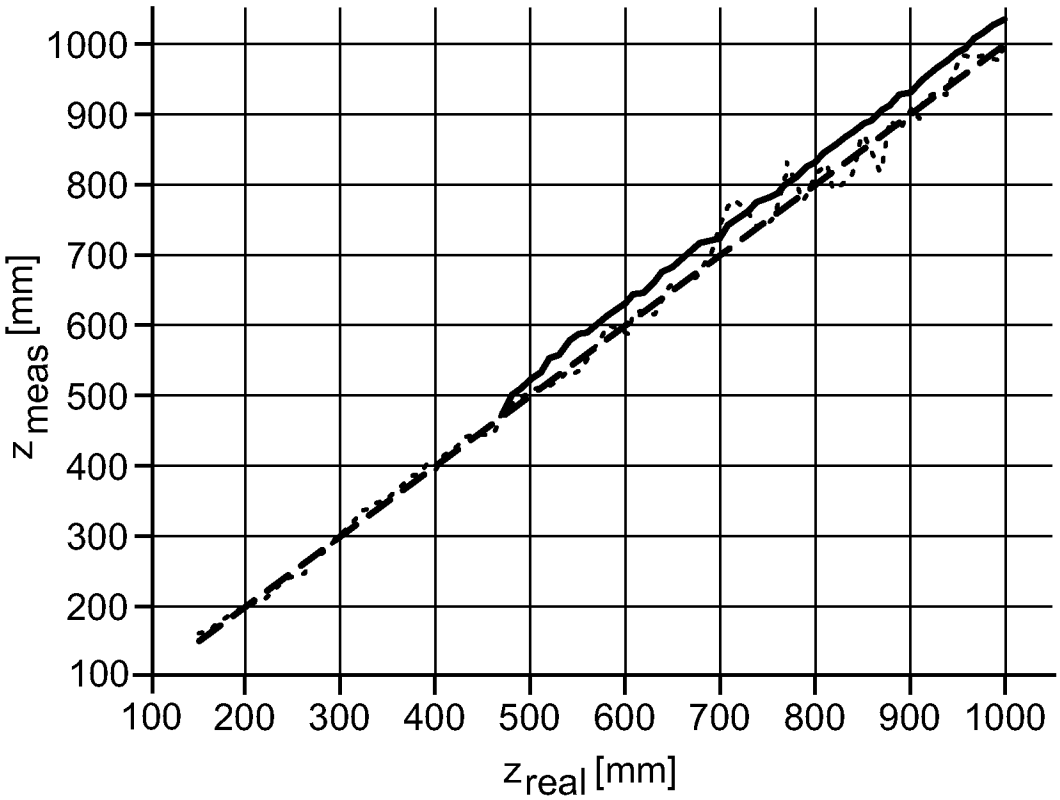

1000
900
800
700
600
500
400
300
200
100
z meas [mm]
100 200 300 400 500 600 700 800 900 1000
z real [mm]

FIG.6A

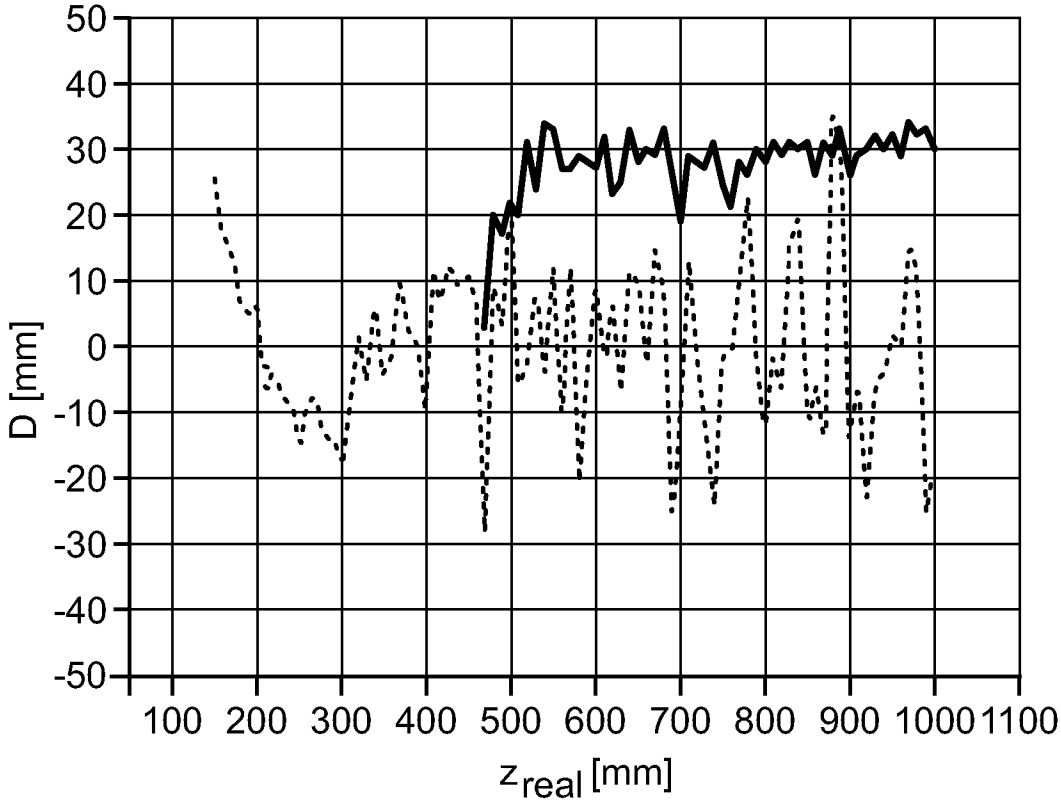

50
40
30
20
10
0
-10
-20
-30
-40
-50
D [mm]
100 200 300 400 500 600 700 800 900 1000 1100
z_{real} [mm]

FIG.6B

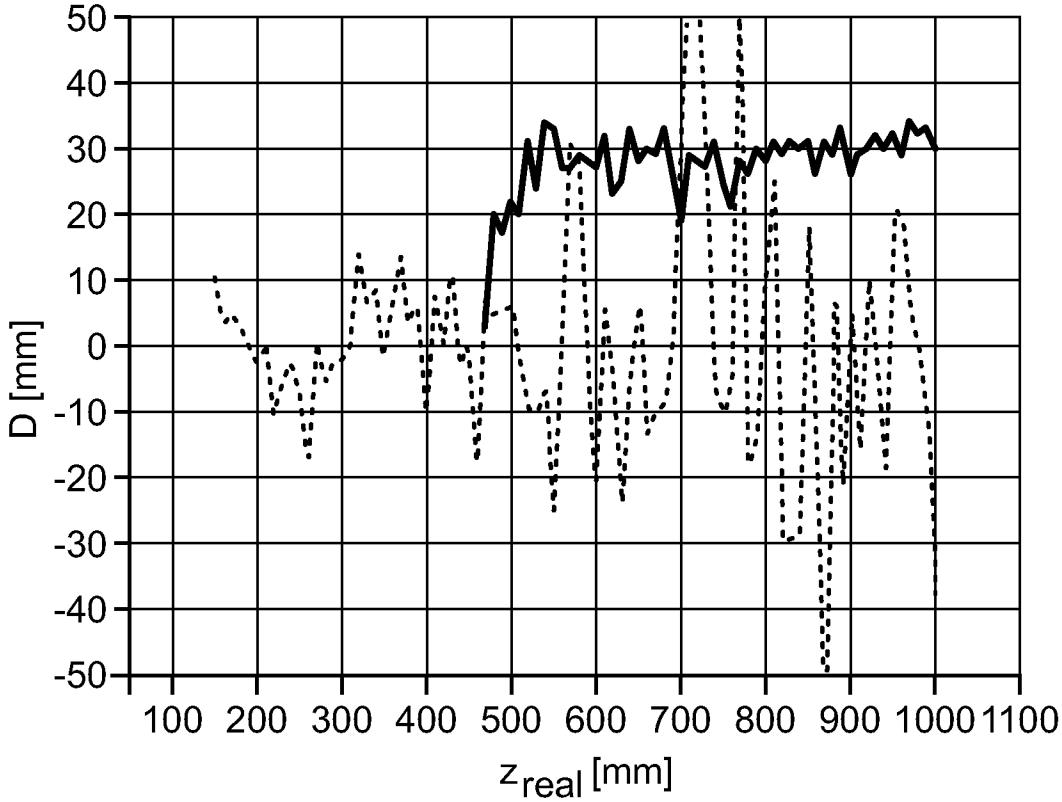

50
40
30
20
10
0
-10
-20
-30
-40
-50
D [mm]
100 200 300 400 500 600 700 800 900 1000 1100
z_{real} [mm]

FIG.7A

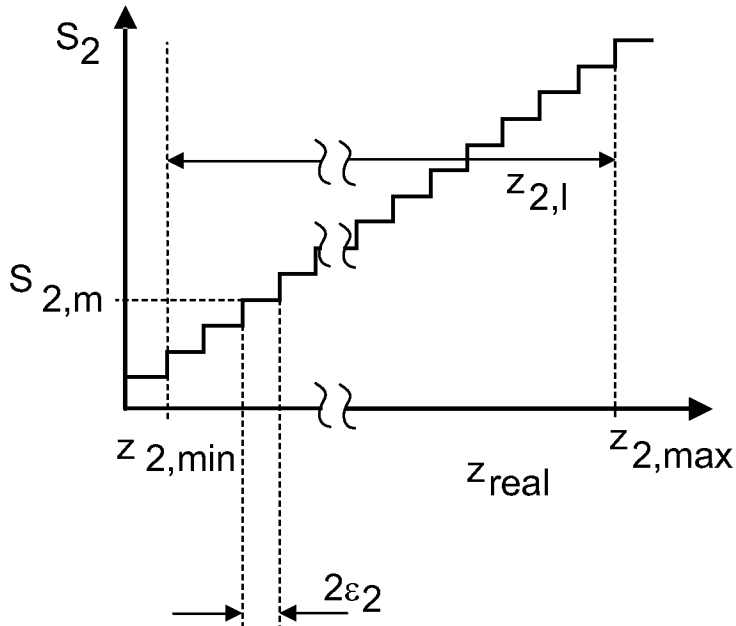

S2
z2,l
S 2,m
z 2,min
z real
z 2,max
2ε2

FIG.7B

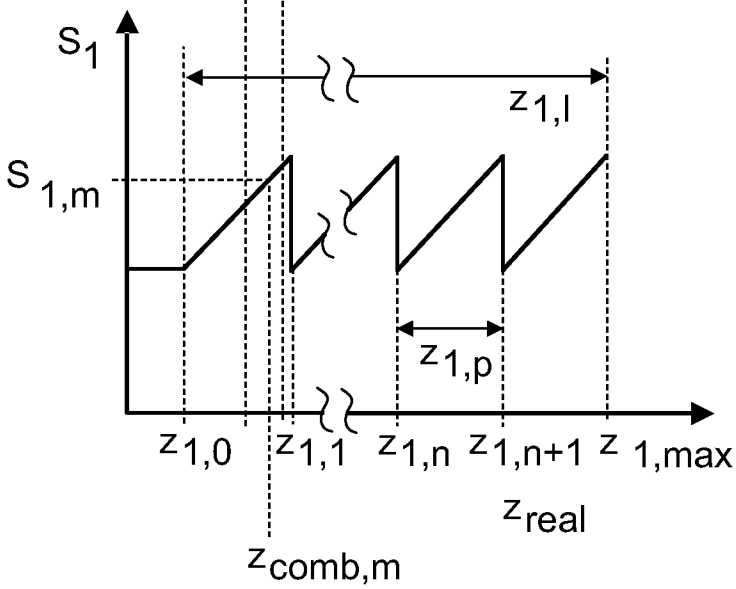

S1
z1,l
S 1,m
z1,p
z1,0
z1,1
z1,n
z1,n+1
z 1,max
z real
z comb,m

FIG.8A

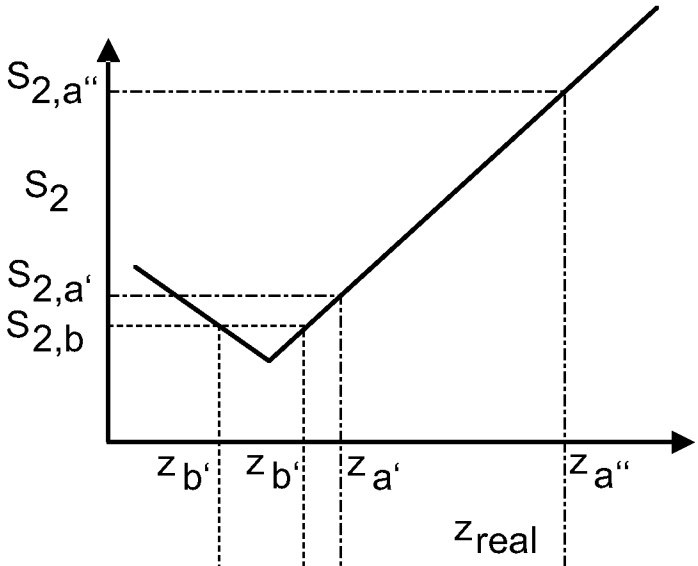


FIG.8B

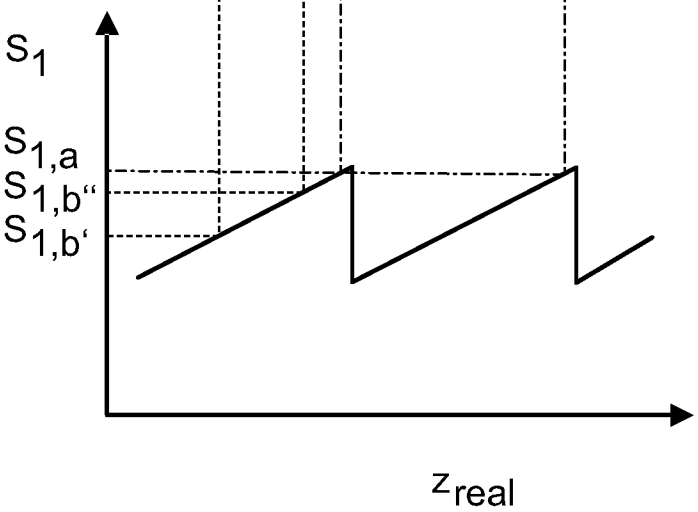


FIG.9A



FIG.9B

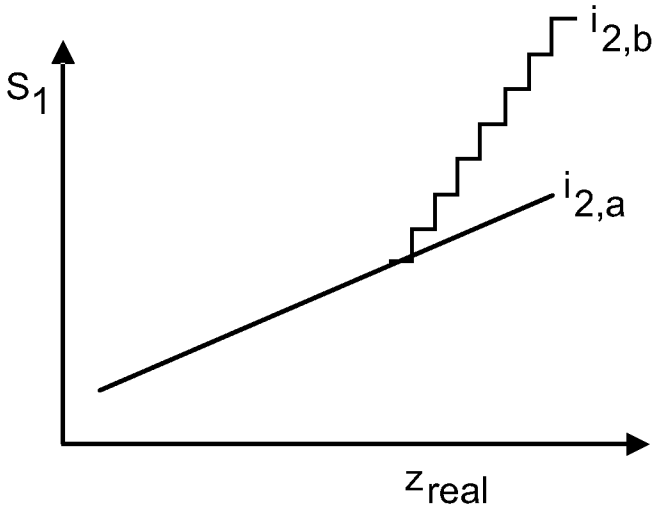


FIG.10A

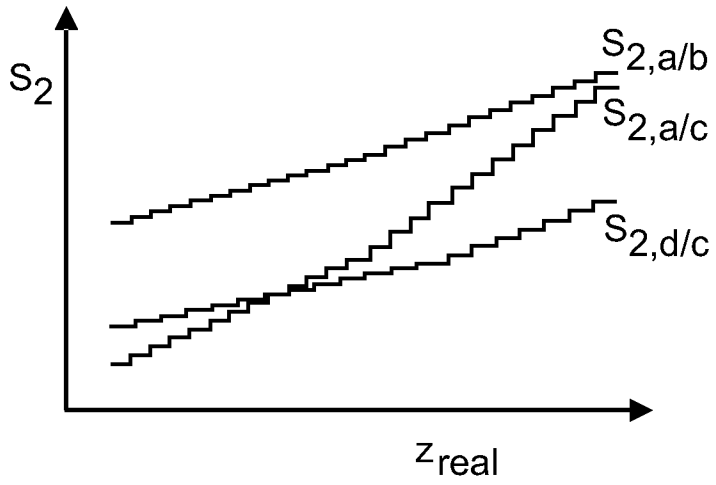


FIG.10B

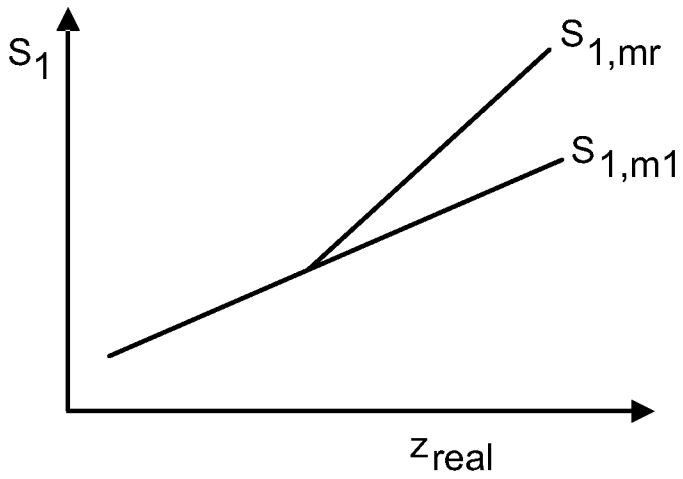


FIG.11

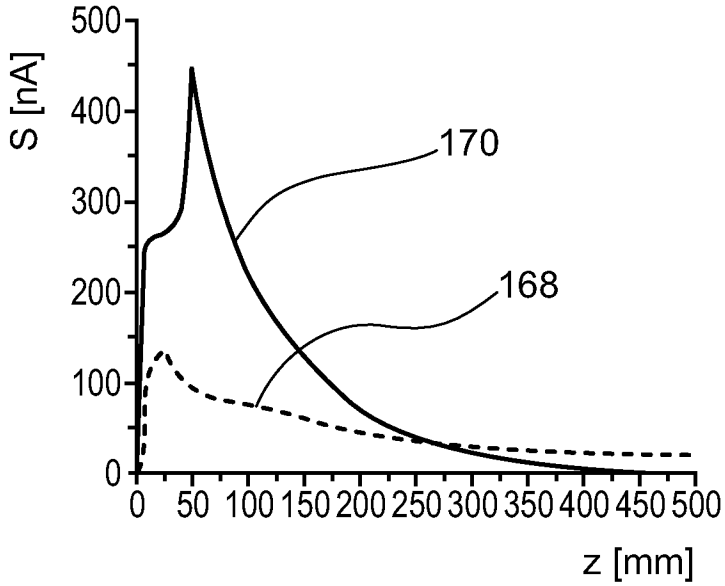

S [nA]
500
400
300
200
100
0
170
168
0 50 100 150 200 250 300 350 400 450 500
z [mm]

FIG.12

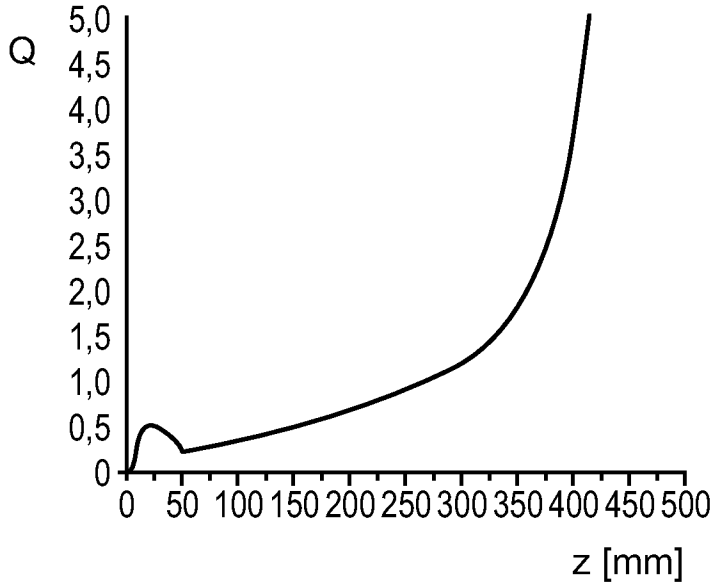

Q
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0
0 50 100 150 200 250 300 350 400 450 500
z [mm]

FIG.13

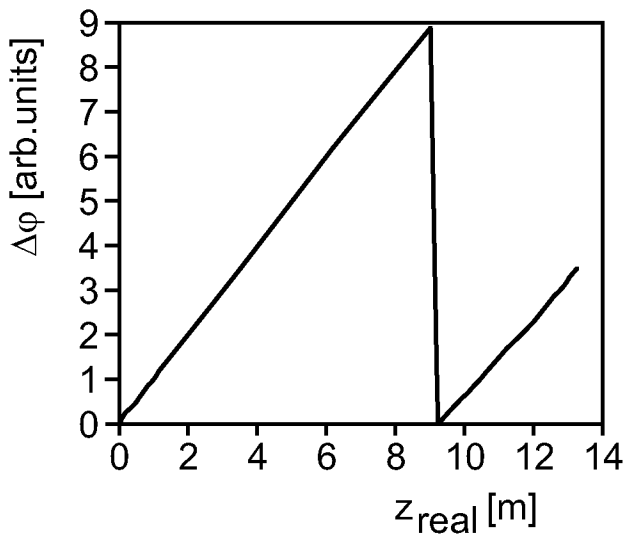


FIG.14

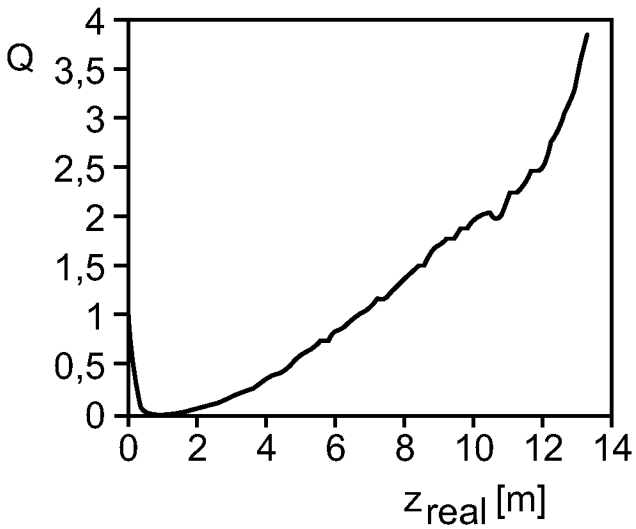
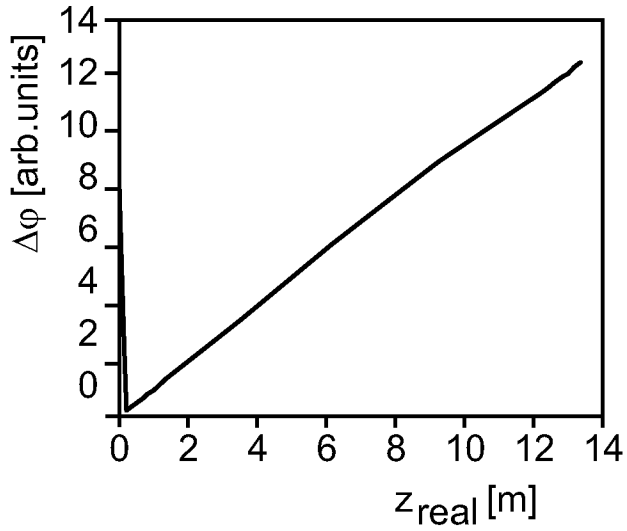


FIG.15



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/068370

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S17/00 G01S17/10 G01S7/481 G01S7/486 G01S17/46
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/127664 A1 (BRUDER INGMAR [DE] ET AL) 5 May 2016 (2016-05-05) abstract; figures 1,2,6,7 page 9, paragraph 98 page 17, paragraph 152-159 pages 18-19, paragraphs 169-172, 174 page 23, paragraph 222 page 29, paragraphs 308, 313 page 33, paragraph 339-341 pages 25-26, paragraph 257-260 -----	1-27
X	US 2011/222075 A1 (TAKAHASHI MASAKI [JP]) 15 September 2011 (2011-09-15) abstract; figures 2,4,6,8 page 4, paragraphs 40,41,43 pages 5-6, paragraph 51-53 ----- -/--	1-5

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
28 September 2018	10/10/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Cordeiro, J

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/068370

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 125 735 A (OIZUMI KOUJI [JP] ET AL) 30 June 1992 (1992-06-30) abstract; figure 1 column 1, line 39 - line 68	1-27
A	US 4 548 504 A (MORANDER KARL-ERIK [SE]) 22 October 1985 (1985-10-22) abstract; figures 1-3 column 4, lines 5-60	1,26,27
A	WO 2013/144649 A1 (SEC DEP FOR BUSINESS INNOVATION & SKILLS [GB]) 3 October 2013 (2013-10-03) abstract; figures 2,9	27

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/068370

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016127664 A1	05-05-2016	AU 2014280332 A1	07-01-2016
		AU 2014280338 A1	07-01-2016
		CN 105452894 A	30-03-2016
		CN 105452895 A	30-03-2016
		EP 3008484 A1	20-04-2016
		EP 3008485 A1	20-04-2016
		JP 2016529473 A	23-09-2016
		JP 2016529474 A	23-09-2016
		KR 20160019065 A	18-02-2016
		KR 20160019901 A	22-02-2016
		US 2016127664 A1	05-05-2016
		US 2016139243 A1	19-05-2016
		US 2018031672 A1	01-02-2018
		US 2018238993 A1	23-08-2018
		WO 2014198623 A1	18-12-2014
		WO 2014198629 A1	18-12-2014
US 2011222075 A1	15-09-2011	JP 5343896 B2	13-11-2013
		JP 2011185817 A	22-09-2011
		US 2011222075 A1	15-09-2011
		US 2013201492 A1	08-08-2013
US 5125735 A	30-06-1992	JP H0361811 A	18-03-1991
		US 5125735 A	30-06-1992
US 4548504 A	22-10-1985	EP 0071667 A1	16-02-1983
		JP H0314124 B2	26-02-1991
		JP S5852514 A	28-03-1983
		US 4548504 A	22-10-1985
WO 2013144649 A1	03-10-2013	CN 104335067 A	04-02-2015
		EP 2831624 A1	04-02-2015
		JP 6256995 B2	10-01-2018
		JP 2015514982 A	21-05-2015
		US 2015085297 A1	26-03-2015
		WO 2013144649 A1	03-10-2013