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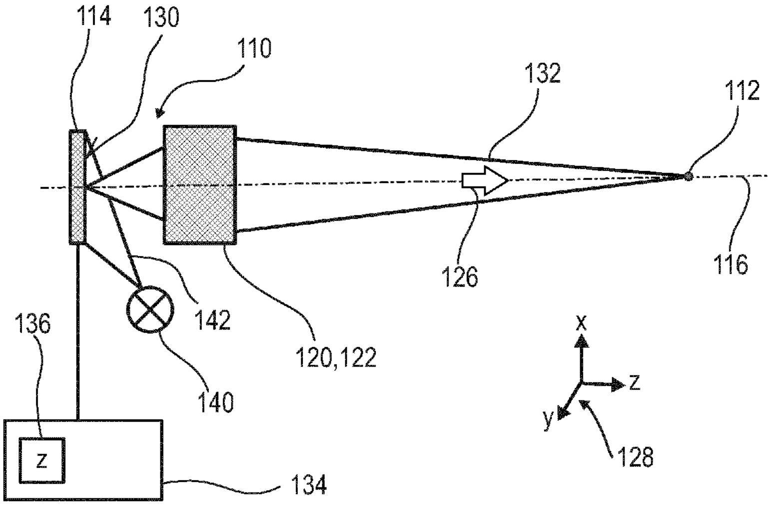
(54) Title: DETECTOR FOR AN OPTICAL DETECTION

FIG.1



(57) **Abstract:** A detector for an optical detection is proposed. The detector comprises: -at least one optical sensor (114), the optical sensor (114) has at least one sensor region (130) for an incident target light beam (132), wherein the sensor region (130) is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region (130) by the target light beam (132), wherein the sensor region(130)comprises at least one semi conducting material; -at least one evaluation device (134), wherein the evaluation device (134) is designed to generate at least one item of information on the target light beam (132) by evaluating the sensor signal; and -at least one bias light source (140), wherein the bias light source (140) is designed to generate at least one bias light beam (142) for at least partially illuminating the sensor region (130).

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Detector for an optical detection

Description

Field of the invention

The invention relates to an optical detector for an optical detection, in particular, of radiation within the infrared spectral range, specifically, with regard to sensing at least one optically conceivable property of an object. More particular, the detector may be used for determining transmissivity, absorption, emission, reflectance, and/or a position of at least one object. Furthermore, the invention relates to a human-machine interface, an entertainment device, a scanning system, a tracking system, a stereoscopic system, and a camera. Further, the invention relates to a method for manufacturing the optical detector and to various uses of the optical detector. Such devices, methods and uses can be employed for example in various areas of daily life, gaming, traffic technology, mapping of spaces, production technology, security technology, medical technology or in the sciences. However, further applications are possible.

Prior art

Various detectors for optically detecting at least one object are known on the basis of optical sensors. WO 2012/110924 A1 discloses a detector comprising at least one optical sensor, wherein the optical sensor exhibits at least one sensor region. Herein, the optical sensor is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region. According to the so-called “FiP effect”, the sensor signal, given the same total power of the illumination, is hereby dependent on a geometry of the illumination, in particular on a beam cross-section of the illumination on the sensor region. The detector furthermore has at least one evaluation device designated 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 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 longitudinal optical sensor. Preferably, a stack of longitudinal optical sensors is employed, in particular to determine a longitudinal position of the object with a high degree of accuracy and without ambiguity. Further, WO 2014/097181 A1 discloses a human-machine interface, an entertainment device, a tracking system, and a camera, each comprising at least one such detector for determining a position of at least one object.

WO 2016/120392 A1 discloses a longitudinal optical sensor 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 hereby dependent on a geometry of the illumination, in particular on a beam cross-section of the illumination on the sensor region. Furthermore, an optical detector is disclosed which has at least one evaluation device designated 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. Herein, a sensor region of the longitudinal optical sensor comprises a photoconductive material, wherein an electrical conductivity in the photoconductive material, given the same total power of the illumination, is dependent on the beam cross-section of the light beam in the sensor region. The photoconductive material may be an inorganic photoconductive material, preferably selected from the group consisting of selenium, a metal oxide, a group IV element or compound, a III-V compound, a II-VI compound, and a chalcogenide, or an organic photoconductive material. Further, a pin diode which comprises a layer of a semiconducting material selected from amorphous silicon (a-Si), hydrogenated amorphous silicon (a-Si:H), hydrogenated microcrystalline silicon (µc-Si:H), hydrogenated amorphous silicon carbon alloy (a-SiC:H), or hydrogenated amorphous germanium silicon alloy (a-GeSi:H) is disclosed. Herein, the pin diode could be employed as optical sensor for an incident beam having a wavelength within one or more of the ultra-violet, visual, or infrared spectral ranges.

Further, European patent application No. 16 164 113.9, filed April 6, 2016 discloses a detector for an optical detection of at least one object, comprising:
- at least one longitudinal optical sensor, the longitudinal optical sensor having at least two individual pin diodes arranged between at least two electrodes, wherein at least one of the pin diodes is designated as a sensor region for an incident light beam, wherein the sensor region is designated to generate at least one longitudinal sensor signal in a manner dependent on an illumination of the sensor region by the light beam, wherein the longitudinal sensor signal, given the same total power of the illumination, is dependent on a beam cross-section of the light beam in the sensor region, and
- at least one evaluation device, wherein the evaluation device is designated to generate at least one item of information on a longitudinal position of the object by evaluating the longitudinal sensor signal. Each of the pin diodes may comprise a material selected from the group consisting of: amorphous silicon (a-Si), an alloy comprising amorphous silicon, microcrystalline silicon (µc-Si), germanium (Ge), indium antimonide (InSb), indium gallium arsenide (InGaAs), indium arsenide (InAs), gallium nitride (GaN), gallium arsenide (GaAs), aluminum gallium phosphide (AlGaP), cadmium telluride (CdTe), mercury cadmium telluride (HgCdTe), copper indium sulfide (CIS), copper indium gallium selenide (CIGS), copper zinc tin sulfide (CZTS), copper zinc tin selenide (CZTSe), copper-zinc-tin sulfur-selenium chalcogenide (CZTSSe), an organic-inorganic halide perovskite, in particular, methylammonium lead iodide (CH3NH3PbI3), and solid solutions and/or doped variants thereof.

W. Hermes, D. Waldmann, M. Agari, K. Schierle-Arndt, and P. Erk, *Emerging Thin-Film Photovoltaic Technologies*, Chem. Ing. Tech. 2015, 87, No. 4, 376–389, provide an overview over thin-film photovoltaic technologies. Herein, an organics-based solar cell, in particular in a dye-sensitized solar cell (DSSC), a kesterite solar cell which, in particular, may comprise a thin film of copper zinc tin sulfide (CZTS), and a hybrid solar cell based on organic-inorganic halide perovskite absorbers, especially on methylammonium lead iodide ($CH_3NH_3PbI_3$), are presented as promising candidates for high solar efficiency.

W. Fuhs, Hydrogenated Amorphous Silicon – Material Properties and Device Applications, in S. Baranovski, Charge Transport in Disordered Solids, Wiley, p. 97-147, 2006, provides an overview about the preparation and structural properties of amorphous silicon (a-Si), hydrogenated amorphous silicon (a-Si:H), and hydrogenated microcrystalline silicon (µc-Si:H). Further, devices comprising amorphous silicon, in particular Schottky barrier diodes, pin diodes, and thin-film solar cells, are presented. As a particular example, a tandem solar cell comprising a stack of two pin diodes is disclosed, wherein photovoltaic materials with different bandgaps are employed in order to increase the total absorption of the solar spectrum. As a further example, a triple junction cell comprising a stack of three pin diodes is disclosed there, wherein a single pin diode comprises an intrinsic a-Si alloy while the two other pin diodes comprise an intrinsic a-SiGe alloy.

Further, WO 2011/091967 A2 discloses a photovoltaic multi-junction thin-film solar cell comprising a carrier substrate, at least one upper sub-cell and at least one lower sub-cell, wherein each of the sub-cells is arranged as a pin structure comprising a p-conducting layer, an n-conducting layer and an intrinsic layer located between the p- conducting layer and the n-conducting layer. The upper sub-cell being adapted for light incidence, in which the intrinsic layer comprises hydrogenated amorphous silicon, is located on the carrier substrate and/or on one or more further layers, whereas the lower sub-cell is located below the upper sub-cell optionally on one or more further intermediate layers. In each sub-cell, the p-conducting layer is located facing towards the incident light. Further, the intrinsic layer in the lower sub-cell requires comprising microcrystalline germanium.

US 2016/364015 A1 describes a detector for determining a position of at least one object. The detector comprising: at least one longitudinal optical sensor, wherein the longitudinal optical sensor has at least one sensor region, wherein the longitudinal optical sensor is at least partially transparent, wherein the longitudinal optical sensor is designed to generate at least one longitudinal sensor signal in a manner dependent on an illumination of the sensor region by at least one light beam traveling from the object to the detector, wherein the longitudinal sensor signal, given the same total power of the illumination, is dependent on a beam cross-section of the light beam in the sensor region; at least one illumination source adapted to illuminate the object with illumination light through the longitudinal optical sensor; and at least one evaluation device, wherein the evaluation device is designed to generate at least one item of information on a longitudinal position of the object by evaluating the longitudinal sensor signal.

Despite the advantages implied by the above-mentioned devices and detectors, optical detectors comprising semiconducting materials, for example amorphous silicon, hydrogenated amorphous silicon, hydrogenated microcrystalline silicon, hydrogenated amorphous silicon carbon alloy or hydrogenated amorphous germanium silicon alloy, show a long term temporal response behavior over several seconds. For example, this behavior can be observed in case the detector is illuminated after a long period of darkness. However, for several applications and purposes immediate or short response behavior is needed.

Problem addressed by the invention

Therefore, a problem addressed by the present invention is that of specifying a device and a method for optically detecting at least one object which at least substantially avoid the disadvantages of known devices and methods of this type. In particular, an improved response behavior would be desirable.

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 herein, the expressions "have", "comprise" and "contain" as well as grammatical variations thereof are used in a non-exclusive way. Thus, the expression "A has B" as well as the expression "A comprises B" or "A contains B" may both refer to the fact that, besides B, A contains one or more further components and/or constituents, and to the case in which, besides B, no other components, constituents or elements are present in A.

In a first aspect of the present invention, a detector for optical detection is disclosed. In particular, the detector may be adapted for determining a position of at least one object, specifically with regard to a depth or to both the depth and a width of the at least one object. 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. As used herein, a “position” generally refers to an arbitrary item of information on a location and/or orientation of the object in space. For this purpose, as an example, one or more coordinate systems may be used, and the position of the object may be determined by using one, two, three or more coordinates. As an example, one or more Cartesian coordinate systems and/or other types of coordinate systems may be used. In one example, the coordinate system may be a coordinate system of the detector in which the detector has a predetermined position and/or orientation. As will be outlined in further detail below, the detector may have an optical axis, which may constitute a main direction of view of the detector. The optical axis may form an axis of the coordinate system, such as a z-axis. Further, one or more additional axes may be provided, preferably perpendicular to the z-axis.

Thus, as an example, the detector may constitute a coordinate system in which the optical axis 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.

As used herein, the detector for optical detection generally may be a device which is adapted for providing at least one item of information on the position of the at least one object. 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 may be adapted to provide the at least one item of information on the position of the at least one object in any feasible way. Thus, the information may e.g. be provided electronically, visually, acoustically or in any arbitrary combination thereof. The information may further be stored in a data storage of the detector or a separate device and/or may be provided via at least one interface, such as a wireless interface and/or a wire-bound interface.

However, other embodiments of optical detection are feasible. In particular, the detector may be adapted for optical detection of concentration of at least one gas, specifically by using absorption bands. For example, the detector may be adapted for providing at least one item of information on a target light beam. The detector may be adapted to determine reduction of the target light beam due to presence of the at least one gas and to determine the concentration therefrom. Furthermore, in particular, the detector may be adapted to determine an intensity of a signal.

The detector for an optical detection according to the present invention comprises:

- at least one optical sensor, the optical sensor has at least one sensor region for an incident target light beam, wherein the sensor region is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region by the light beam, wherein the sensor region comprises at least one semiconducting material;
- at least one evaluation device, wherein the evaluation device is designed to generate at least one item of information of the target light beam by evaluating the sensor signal; and
- at least one bias light source, wherein the bias light source is designed to generate at least one bias light beam for at least partially illuminating the sensor region.

Herein, the components listed above may be separate components. Alternatively, two or more of the components as listed above may be integrated into one component. Further, the at least one evaluation device may be formed as a separate evaluation device independent from the transfer device and the longitudinal optical sensors, but may preferably be connected to the longitudinal optical sensors in order to receive the longitudinal sensor signal. Alternatively, the at least one evaluation device may fully or partially be integrated into the longitudinal optical sensors.

As used herein, the “optical sensor” is generally a device which is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region by the target light beam. The optical sensor may be a longitudinal optical sensor. In the following, the optical sensor is denoted as longitudinal optical sensor. However, other embodiments are feasible wherein the optical sensor is another optical sensor than a longitudinal optical sensor. The sensor region may be designed to generate at least one longitudinal sensor signal in a manner dependent on an illumination of the sensor region by the target light beam, wherein the longitudinal sensor signal, given the same total power of the illumination, is dependent on a beam cross-section of the target light beam in the sensor region. The evaluation device may be designed to generate at least one item of information on a longitudinal position of the object by evaluating the longitudinal sensor signal.

The longitudinal sensor signal, given the same total power of the illumination, may be dependent, according to the so-called “FiP effect” on a beam cross-section of the target light beam in the sensor region. The longitudinal sensor signal may generally be an arbitrary signal indicative of the longitudinal position, which may also be denoted as a depth. As an example, the longitudinal sensor signal may be or may comprise a digital and/or an analog signal. As an example, the longitudinal sensor signal may be or may comprise a voltage signal and/or a current signal. Additionally or alternatively, the longitudinal sensor signal may be or may comprise digital data. The longitudinal sensor signal may comprise a single signal value and/or a series of signal values. The longitudinal sensor signal may further comprise an arbitrary signal which is derived by combining two or more individual signals, such as by averaging two or more signals and/or by forming a quotient of two or more signals. For potential embodiments of the longitudinal optical sensor and the longitudinal sensor signal, reference may be made to the optical sensor as disclosed in WO 2012/110924 A1.

As used herein, the term “sensor region” generally refers to a two-dimensional or three-dimensional region which preferably, but not necessarily, is continuous and can form a continuous region, wherein the sensor region is designed to vary at least one measurable property, in a manner dependent on the illumination. By way of example, said at least one property can comprise an electrical property, for example, by the sensor region being designed to generate, solely or in interaction with other elements of the optical sensor, a photovoltage and/or a photocurrent and/or some other type of signal. In particular the sensor region can be embodied in such a way that it generates a uniform, preferably a single, signal in a manner dependent on the illumination of the sensor region. The sensor region can thus be the smallest unit of the longitudinal optical sensor for which a uniform signal, for example, an electrical signal, is generated, which preferably can no longer be subdivided to partial signals, for example for partial regions of the sensor region. The longitudinal optical sensor can have one or else a plurality of such sensor regions, the latter case for example by a plurality of such sensor regions being arranged in a two-dimensional and/or three-dimensional matrix arrangement.

The sensor region specifically may be oriented towards the object. As used herein, the term “is oriented towards the object” generally refers to the situation that a surface of the sensor region is 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 sensor region 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°-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.

Preferably, the sensor region of may be formed by one continuous sensor region, such as one continuous sensor area or sensor surface per device. Thus, preferably, the sensor region of the longitudinal optical sensor or, in case a plurality of longitudinal optical sensors is provided (such as a stack of longitudinal optical sensors), each sensor region of the longitudinal optical sensor, may be formed by exactly one continuous sensor region.

The at least one optical sensor may have a sensor region providing a sensitive area, also referred to as a sensor area, of at least 1 mm², preferably of at least 5 mm², such as a sensor area of 5 mm² to 1000 cm², preferably a sensor area of 7 mm² to 100 cm², more preferably a sensor area of 1 cm². The sensor area preferably has a rectangular geometry, such as a square geometry. However, other geometries and/or sensor areas are feasible.

The sensor region comprises at least one semiconducting material. In particular, the sensor region comprises at least one material capable of sustaining an electrical current. At least one property of the material, given the same total power of the illumination, may be dependent on the beam cross-section of the target light beam in the sensor region. Herein, at least one property of the material, being the electrical conductivity of the material or another material property, such as a thermal conductivity, an absorbance, a scattering property, a dielectric property, a magnetic property, or an optical property of the material, in particular a polarization, a reflectance, a refractive index, or a transmission, of the material, given the same total power of the illumination, is dependent on the beam cross-section of the target light beam in the sensor region. As a result, the longitudinal sensor signal may be dependent on the at least one property of the material. Consequently, measuring the at least one property by recoding the at least one longitudinal sensor signal allows determining the beam cross-section of the target light beam in the sensor region and, generating at least one item of information on a longitudinal position of the object. Herein, the longitudinal signal may be an electrical signal, such as a voltage or a current, but may, first, be a physical signal of a different kind, in particular an optical signal, which may, thereafter, be transformed into an electrical signal, which may, then, be further treated as the longitudinal sensor signal.

The semiconducting material may comprise a material selected from the group consisting of: amorphous silicon (a-Si); an alloy comprising amorphous silicon; hydrogenated amorphous silicon (a-Si:H); microcrystalline silicon (μc-Si); hydrogenated microcrystalline silicon (μc-Si:H); hydrogenated amorphous silicon carbon alloy (a-SiC:H), hydrogenated amorphous germanium silicon alloy (a-GeSi:H); microcrystalline CIGS; microcrystalline CIS; microcrystalline CZTS; microcrystalline CdTe; crystalline silicon (c-Si); crystalline germanium (c-Ge); crystalline Silicon Germanium alloy (c-SiGe); extrinsic silicon; extrinsic germanium; InGaAs; extended InGaAs; InAs; InSb; GaP; GaN; SiC; organic semiconductors; a semiconductive metal oxid, in particular a n-conductive semiconductive metal oxid, for example titanium dioxide (TiO_2), in particular dye sensitized titanium dioxide (TiO_2). As generally used, the term “amorphous silicon” relates to a non-crystalline allotropic form of silicon. As further known from the state of the art, the amorphous silicon can be obtained by depositing it as a layer, especially as a thin film, onto an appropriate substrate. However, other methods may be applicable. Further, the amorphous silicon may especially be passivated by using hydrogen, by which application a number of dangling bonds within the amorphous silicon may be reduced by several orders of magnitude. As a result, hydrogenated amorphous silicon, usually abbreviated to “a-Si:H”, may exhibit a low amount of defects, thus, allow using it for optical devices.

For example, with respect to design of the longitudinal optical sensor and sensor region reference may be made to the optical sensor as disclosed in WO 2016/120392 A1. The longitudinal optical sensor may be a photo detector having at least one first electrode and at least one second electrode while the amorphous silicon may, preferably, be located between the first electrode and the second electrode. In particular for a purpose of facilitating the light beam which may impinge the longitudinal optical sensor to arrive at a layer comprising the amorphous silicon, at least one of the electrodes, in particular the electrode which may be located within the path of the incident light beam, may be selected to be at least partially optically transparent. Herein, the at least partially optically transparent electrode may comprise at least one transparent conductive oxide (TCO), in particular at least one of indium-doped tin oxide (ITO), fluorine-doped tin oxide (FTO), aluminum-doped zinc oxide (AZO), or a perovskite TCO, such as SrVO3, or CaVO3, or, alternatively, metal nanowires, in particular Ag or Cu nanowires. However, other kinds of optically transparent materials which may be suited as electrode material may also be applicable. The one or more remaining electrodes, also denominated as “back electrodes”, may also be optically intransparent, in particularly as long as they are located outside the path of the light beam within the longitudinal optical sensor. Herein, the at least one optically intransparent electrode may, preferably, comprise a metal electrode, in particular one or more of a silver (Ag) electrode, a platinum (Pt) electrode, an aluminum (Al) electrode, or a gold (Au) electrode, or, alternatively, a graphene electrode. Preferably, the optically intransparent electrode may comprise a uniform metal layer. Alternatively, the optically intransparent electrode may be a split electrode being arranged as a number of partial electrodes or in form of a metallic grid.

Preferably, the amorphous silicon which is located between the first electrode and the second electrode may be arranged in form of a PIN diode. As generally used, the term “PIN diode” refers to an electronic device which comprises an i-type semiconductor layer that is located between an n-type semiconductor layer and a p-type semiconductor layer. As known from the state of the art, while in the n-type semiconducting layer charge carriers are predominantly provided by electrons, in the p-type semiconducting layer the charge carriers are predominantly provided by holes. In a preferred embodiment, the p-type semiconducting layer can partially or wholly be comprised of amorphous silicon carbide. Further, the i-type semiconducting layer comprises an undoped intrinsic amorphous silicon. In particular, in the longitudinal optical sensor according to the present invention, the i-type semiconductor layer may exhibit a thickness which may exceed the thickness of each of the n-type semiconductor layer and the p-type semiconductor layer, in particular by a factor of at least 2, preferably of at least 5, more preferred of at least 10 or more. As an example, the thickness of the i-type semiconducting layer may be from 100 nm to 3000 nm, in particular from 600 nm to 800 nm, whereas the thickness of both the n-type and the p-type semiconductor layer may be from 5 nm to 100 nm, in particular from 10 nm to 60 nm.

Photovoltaic diodes which are provided in the form of a PIN diode comprising amorphous silicon are, generally, known to exhibit a non-linear frequency response. As a result, the positive and/or the negative FiP effect may be observable in the longitudinal sensor which may, moreover, be substantially frequency-independent in a range of a modulation frequency of the light beam of 0 Hz to 50 kHz. With respect to experimental results which demonstrate an occurrence of the mentioned features reference is made to WO 2016/120392 A1. Further, the optical detector comprising the amorphous silicon may exhibits the particular advantages of abundance of the respective semiconducting material, of an easy production route, and of a considerably high signal-to-noise ratio compared to other known FiP devices.

Further, taking into account a behavior of an external quantum efficiency of the PIN diode vs. the wavelength of the incident beam may provide insight into a wavelength range of the incident beam for which the PIN diode may particularly be suitable. Herein, the term “external quantum efficiency” refers to a fraction of photon flux which may contribute to the photocurrent in the present sensor. As a result, the PIN diode which comprises the amorphous silicon may exhibit a particularly high value for the external quantum efficiency within the wavelength range which may extend from 380 nm to 700 nm whereas the external quantum efficiency may be lower for wavelengths outside this range, in particular for wavelengths below 380 nm, i.e. within the UV range, and for wavelengths above 700 nm, in particular within the NIR range, thereby being vanishingly small above 800 nm. Consequently, the PIN diode which the amorphous silicon in at least one of the semiconductor layers may preferably be employed in the detector according to the present invention for the optical detection of the at least one object when the incident beam has a wavelength within a range which covers most of the visual spectral range, especially from 380 nm to 700 nm.

Alternatively, a further PIN diode may be provided which could preferably be employed in the detector according to the present invention when the incident beam may have a wavelength within the UV spectral range. As used herein, the term “UV spectral range” may cover a partition of the electromagnetic spectrum from 1 nm to 400 nm, in particular from 100 nm to 400 nm, and can be subdivided into a number of ranges as recommended by the ISO standard ISO-21348, wherein the alternative PIN diode provided here may particularly be suitable for the Ultraviolet A range, abbreviated to “UVA”, from 400 nm to 315 nm and/or the Ultraviolet B range, abbreviated to “UVB” from 315 nm to 280 nm. For this purpose, the alternative PIN diode may exhibit the same or a similar arrangement as the PIN diode comprising the amorphous silicon as described above and/or below, wherein the amorphous silicon (a-Si) or the hydrogenated amorphous silicon (a-Si:H), respectively, may at least partially be replaced by an amorphous alloy of silicon and carbon (a-SiC) or, preferably, by a hydrogenated amorphous silicon carbon alloy (a-SiC:H). This kind of alternative PIN diode may exhibit a high external quantum efficiency within the UV wavelength range preferably, over the complete UVA and UVB wavelength range from 280 nm to 400 nm. Herein, the hydrogenated amorphous silicon carbon alloy (a-SiC:H) may, preferably, be produced in a plasma-enhanced deposition process, typically by using SiH4 and CH4 as process gases. However, other production methods for providing a-SiC:H may also be applicable.

Alternatively, a further PIN diode may be provided which could preferably be employed in the detector according to the present invention when the incident beam may have a wavelength within the NIR spectral range. As used herein, the term “NIR spectral range”, which may also abbreviated to “IR-A”, may cover a partition of the electromagnetic spectrum from 760 nm to 1400 nm as recommended by the ISO standard ISO-21348. For this purpose, the alternative PIN diode may exhibit the same or a similar arrangement as the PIN diode comprising the amorphous silicon as described above and/or below, wherein the amorphous silicon (a-Si) or the hydrogenated amorphous silicon (a-Si:H), respectively, may at least partially be replaced by one of a microcrystalline silicon (μc-Si), preferably a hydrogenated microcrystalline silicon (μc-Si:H), or an amorphous alloy of germanium and silicon (a-GeSi), preferably a hydrogenated amorphous germanium silicon alloy (a-GeSi:H). This further kind of PIN diode may exhibit a high external quantum efficiency over a wavelength range which may at least partially cover the NIR wavelength range from 760 nm to 1400 nm, in particular at least from 760 nm to 1000 nm. By way of example, the PIN diode comprising μc-Si has a non-negligible quantum efficiency over a wavelength range which approximately extends from 500 nm to 1100 nm.

Herein, the hydrogenated microcrystalline silicon (μc-Si:H) may, preferably, be produced from a gaseous mixture of SiH_4 and CH_4. As a result, a two-phase material on a substrate comprising microcrystallites having a typical size of 5 nm to 30 nm and being located between ordered columns of the substrate material spaced apart 10 nm to 200 nm with respect to each other may be obtained. However, another production method for providing μc-Si:H may also be applicable which may, however not necessarily, lead to an alternative arrangement of the μc-Si:H. Further, the hydrogenated amorphous germanium silicon alloy (a-GeSi:H) may, preferably, be produced by using SiH_4, GeH_4, and H_2 as process gases within a common reactor. Also here, other production methods for providing a-GeSi:H may be feasible.

Comparing both µc-Si:H and a-GeSi:H to a-Si:H, the semiconductor layers comprising µc-Si:H and a-GeSi:H may have a similar or an increased disorder-induced localization of charge carriers, thus, exhibiting a considerably non-linear frequency response. As described above, this may constitute a basis for the occurrence of the FiP effect in the longitudinal sensor being equipped with a PIN diode comprising these kinds of semiconductor layers. As a result, this kind of longitudinal sensors may, in particular, be used in applications in which a NIR response may be required, such as in night vision or fog vision, or suitable, such as when an active target emitting at least one wavelength within the NIR spectral range may be used, for example, in a case in which it might be advantageous when animals or human beings may be left undisturbed by using an NIR illumination source.

For the purpose of the present invention, the sensor region of the longitudinal optical sensor is illuminated by the at least one target light beam. Given the same total power of the illumination, an electrically detectable property of the sensor region, therefore, depends on a beam cross-section of the light beam in the sensor region, which may also be denominated as a “spot size” generated by the incident light beam within the sensor region. Thus, the electrically detectable property which depends on an extent of the illumination of the sensor region by an incident light beam particularly accomplishes that two light beams comprising the same total power but generating different spot sizes on the sensor region provide different values for the electrically detectable property in the sensor region and are, consequently, distinguishable with respect to each other.

As used herein, the term “light” generally refers to electromagnetic radiation in one or more of the visible spectral range, the ultraviolet spectral range and the infrared spectral range. Therein, in partial accordance with ISO standard ISO-21348, the term visible spectral range generally refers to a spectral range of 380 nm to 760 nm. The term infrared (IR) spectral range generally refers to electromagnetic radiation in the range of 760 nm to 1000 µm, wherein the range of 760 nm to 1.4 µm is usually denominated as the near infrared (NIR) spectral range, and the range from 15 µm to 1000 µm as the far infrared (FIR) spectral range. The term ultraviolet spectral range generally refers to electromagnetic radiation in the range of 1 nm to 380 nm, preferably in the range of 100 nm to 380 nm. Preferably, light as used within the present invention is visible light, i.e. light in the visible spectral range.

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. Thus, the light beam may be a bundle of the light rays having a predetermined extension in a direction perpendicular to a direction of propagation of the light beam. The light beam specifically may be a Gaussian light beam, as will be outlined in further detail below. Other embodiments are feasible, however.

As used herein, the term “target light beam”, also denoted as light beam or light beam originating from the object, generally refers to a measurement light beam and/or signal light beam. The target light beam may be generated by a reflection of an illumination and/or radiation on the object and/or the gas, and/or by light emission by the object and/or the gas itself, for example stimulated by the radiation originating from the object and/or the gas. In particular, the target light beam may be a light beam originating from the object, in particular which is generated by a reflection of an illumination and/or radiation on the object and/or by light emission by the object itself, for example stimulated by the radiation. In the following the target light beam may be denoted as light beam whereas the light beam generated by the bias light source may be denoted as bias light beam. For example, at least one illumination source may be 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 and, thereby, is at least partially directed towards the detector. The illumination source, as an example, may be or may comprise one or more of an external illumination source, an illumination source integrated into the detector or an illumination source integrated into a beacon device being one or more of attached to the object, integrated into the object or held by the object.

Further, since the beam cross-section of the light beam in the sensor region, according to the above-mentioned FiP effect, given the same total power of the illumination, depends on the longitudinal position or depth of an object which emits or reflects the light beam that impinges on the sensor region, the longitudinal optical sensor may, therefore, be applied to determining a longitudinal position of the respective object.

As already known from WO 2012/110924 A1, the longitudinal optical sensor is designed to generate at least one longitudinal sensor signal in a manner dependent on an illumination of the sensor region, wherein the sensor signal, given the same total power of the illumination depends on a beam cross-section of the illumination on the sensor region. As an example, a measurement of a photocurrent I as a function of a position of a lens is provided there, wherein the lens is configured for focusing electromagnetic radiation onto the sensor region of the longitudinal optical sensor. During the measurement, the lens is displaced relative to the longitudinal optical sensor in a direction perpendicular to the sensor region in a manner that, as a result, the diameter of the light spot on the sensor region changes. In the present case in which at least one pin diode is designed as the sensor region, the signal of the longitudinal optical sensor, in particular a photocurrent, clearly depends on the geometry of the illumination such that, outside a maximum at the focus of the lens, the photocurrent falls to less than 10% of its maximum value.

This effect is particularly striking with respect to similar measurements performed by using optical sensors of a conventional type in which the sensor signal, given the same total power, is substantially independent of a geometry of the illumination of the sensor region. Thus, according to the FiP effect, the longitudinal sensor signal, given the same total power, may exhibit at least one pronounced maximum for one or a plurality of focusings and/or for one or a plurality of specific sizes of the light spot on the sensor region or within the sensor region. For purposes of comparison, an observation of a maximum of the longitudinal sensor signal in a condition in which the corresponding material is impinged by a light beam with the smallest possible cross-section, such as when the material may be located at or near a focal point as affected by an optical lens, may be denominated as a “positive FiP effect”. Alternatively, a “negative FiP effect” may be observable, which, in correspondence to the definition of the positive FiP effect, describes an observation of a minimum of the longitudinal sensor signal under a condition in which the corresponding material is impinged by a light beam with the smallest available beam cross-section, in particular, when the material may be located at or near a focal point as effected by an optical lens. As will be illustrated below, an appearance of the negative FiP effect may be observed in the longitudinal optical sensor according to the present invention.

As used herein, the term “evaluation device” generally refers to an arbitrary device designed to generate the items of information, in particular the at least one item of information on the position of the object and/or at least one item of information on the reduction of the target light beam. As an example, 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 field programmable gate arrays (FPGAs), and/or digital signal processors (DSPs), and/or one or more data processing devices, such as one or more computers, preferably one or more microcomputers and/or microcontrollers. 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. As used herein, the sensor signal may generally refer to one of the longitudinal sensor signal and, if applicable, to the transversal sensor signal. Further, the evaluation device may comprise one or more data storage devices. Further, as outlined above, 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 performing or supporting the step of generating the items of information. As an example, one or more algorithms may be implemented which, by using the sensor signals as input variables, may perform a predetermined transformation into the position of the object.

The evaluation device may particularly comprise at least one data processing device, in particular an electronic data processing device, which can be designed to generate the items of information by evaluating the sensor signals. Thus, the evaluation device is designed to use the sensor signals as input variables and to generate the items of information on the transversal position and the longitudinal position of the object by processing these input variables. The processing can be done in parallel, subsequently or even in a combined manner. The evaluation device may use an arbitrary process for generating these items of information, such as by calculation and/or using at least one stored and/or known relationship. Besides the sensor signals, one or a plurality of further parameters and/or items of information can influence said relationship, for example at least one item of information about a modulation frequency. The relationship can be determined or determinable empirically, analytically or else semi-empirically. Particularly preferably, the relationship comprises at least one calibration curve, at least one set of calibration curves, at least one function or a combination of the possibilities mentioned. One or a plurality of calibration curves can be stored for example in the form of a set of values and the associated function values thereof, for example in a data storage device and/or a table. Alternatively or additionally, however, the at least one calibration curve can also be stored for example in parameterized form and/or as a functional equation. Separate relationships for processing the sensor signals into the items of information may be used. Alternatively, at least one combined relationship for processing the sensor signals is feasible. Various possibilities are conceivable and can also be combined.

By way of example, the evaluation device can be designed in terms of programming for the purpose of determining the items of information. The evaluation device can comprise in particular at least one computer, for example at least one microcomputer. Furthermore, the evaluation device can comprise one or a plurality of volatile or nonvolatile data memories. As an alternative or in addition to a data processing device, in particular at least one computer, the evaluation device can comprise one or a plurality of further electronic components which are designed for determining the items of information, for example an electronic table and in particular at least one look-up table and/or at least one application-specific integrated circuit (ASIC).

The detector has, as described above, at least one evaluation device. In particular, the at least one evaluation device can also be designed to completely or partly control or drive the detector, for example by the evaluation device being designed to control at least one illumination source for illumination of the object and/or control the bias light source and/or to control at least one modulation device of the detector. The evaluation device can be designed, in particular, to carry out at least one measurement cycle in which one or a plurality of sensor signals, such as a plurality of sensor signals, are picked up, for example a plurality of sensor signals of successively at different modulation frequencies of the illumination.

Generally, the item of information on the target light beam may be selected from the group consisting of at least one location information, in particular on the position of the object; at least one intensity information, in particular at least one concentration information.

The evaluation device may be designed, as described above, to generate at least one item of information on the position of the object by evaluating the at least one sensor signal. Said position of the object can be static or may even comprise at least one movement of the object, for example a relative movement between the detector or parts thereof and the object or parts thereof. In this case, a relative movement can generally comprise at least one linear movement and/or at least one rotational movement. Items of movement information can for example also be obtained by comparison of at least two items of information picked up at different times, such that for example at least one item of location information can also comprise at least one item of velocity information and/or at least one item of acceleration information, for example at least one item of information about at least one relative velocity between the object or parts thereof and the detector or parts thereof. In particular, the at least one item of location information can generally be selected from: an item of information about a distance between the object or parts thereof and the detector or parts thereof, in particular an optical path length; an item of information about a distance or an optical distance between the object or parts thereof and the optional transfer device or parts thereof; an item of information about a positioning of the object or parts thereof relative to the detector or parts thereof; an item of information about an orientation of the object and/or parts thereof relative to the detector or parts thereof; an item of information about a relative movement between the object or parts thereof and the detector or parts thereof; an item of information about a two-dimensional or three-dimensional spatial configuration of the object or of parts thereof, in particular a geometry or form of the object. Generally, the at least one item of location information can therefore be selected for example from the group consisting of: an item of information about at least one location of the object or at least one part thereof; information about at least one orientation of the object or a part thereof; an item of information about a geometry or form of the object or of a part thereof, an item of information about a velocity of the object or of a part thereof, an item of information about an acceleration of the object or of a part thereof, an item of information about a presence or absence of the object or of a part thereof in a visual range of the detector.

Additionally or alternatively, the evaluation device may be designed to generate at least one intensity information, in particular one item of information on the reduction of the target light beam, and to determine a concentration of at least one gas therefrom.
The at least one item of location information can be specified for example in at least one coordinate system, for example a coordinate system in which the detector or parts thereof rest. Alternatively or additionally, the location information can also simply comprise for example a distance between the detector or parts thereof and the object or parts thereof. Combinations of the possibilities mentioned are also conceivable.

The detector comprises the at least one bias light source. The bias light source is designed to generate at least one bias light beam for at least partially illuminating the sensor region. The bias light source may be designed to generate the at least one bias light beam for illuminating the whole sensor region. As used herein, the term “partially illuminating” refers to an illumination of the sensor region, wherein partial areas of the sensor region are illuminated, for example areas in which the target light beam, in particular the light beam from the object, impinges and/or is expected to impinge, whereas other areas of the sensor region are omitted. Preferably, the bias light source is adapted to illuminate 50% of the sensor region, more preferably 70 % and most preferably the whole sensor region. As used herein, the term “bias light beam” refers to at least one light beam adapted to illuminate the sensor region or parts of the sensor region in addition to and independent from the light beam originating from the object. In particular, the bias light source may be arranged such that the object is not or to a minimum extend illuminated by the bias light beam. For example, the bias light source may be arranged such that the bias light beam impinges on the sensor region directly, i.e. without previously illuminating the object and without being reflected by the object. The detector and/or the bias light source may comprise optical elements, such as at least one mirror and/or at least one lens, adapted to direct the bias light beam on the sensor region. As used herein, the term “bias light source” refers to an arbitrary light source adapted to generate the bias light beam, and thus, to a light source adapted to provide illumination of the sensor region in addition to and independent from the light beam originating from the object. The bias light source may be adapted not to illuminate the object. In particular, the bias light source may be arranged such that the bias light source illuminates the sensor region without illuminating the object. For example, the bias light source may comprise at least one opening such as at least one aperture adapted to align and/or orientate the bias light beam, in particular a direction of propagation of the bias light beam, towards the sensor region. The bias light source may be adapted to generate the bias light beam such that the direction of propagation of the bias light beam is opposite to a direction of the at least one target light beam illuminating the object. The bias light source and the optical sensor may be arranged as such that the direction of the propagation bias light beam is essentially orthogonal to at least one optical axis of the optical sensor. As used herein, the term “essentially orthogonal to the optical axis” refers to orthogonal with a tolerance of e.g. ±10% or less, preferably a tolerance of ±5% or less, more preferably a tolerance of ±1% or less. The bias light beam and the target light beam, in particular the light beam originating from the object, may have different beam properties. For example, wavelength and/or modulation frequency and /or luminosity and/or brightness and/or intensity of the bias light beam may be different than luminosity and/or brightness and/or intensity of the target light beam.

The bias light beam may be monochromatic or polychromatic. In particular, the bias light beam may be polychromatic within a small wavelength range, for example, within the IR-wavelength range. The wavelength and/or wavelength range of the bias light beam may be adjustable. The bias light source may comprise at least one monochromatic light source, e.g. at least one laser source, in particular a laser diode, and/or at least one light emitting diode. The bias light source may be at least one incandescent lamp, at least one heater element or other element at elevated temperature. The temperature can be tuned to supply the intended spectral range. Alternatively, the bias light source may comprise at least one polychromatic light source and at least one filter element adapted to adjust the wavelength of the bias light beam. The bias light source may be adapted to generate a long wavelength illumination. In particular, the bias light beam may have a long wavelength. The bias light source may comprise at least one infrared light source. The bias light beam may have a wavelength in the infrared spectral range, preferably within the near infrared (NIR) spectral range. The bias light beam may have a different or same wavelength as the target light beam.

The bias light source may be adapted to uniformly illuminate the sensor region. As used herein, the term “uniformly illuminate” refers to one or more of a constant, permanent and homogenous illumination of the sensor region. In particular, the bias light source may be adapted to illuminate uniformly the sensor region during an entire measurement time and/or a measurement interval. The illumination with the bias light beam may be homogenous on the sensor region. In particular, the bias light source may be adapted to illuminate the entire sensor region or the illuminated parts of the sensor region with essential equal luminosity and/or brightness and/or intensity. As used herein, the term “essential equal” refers to the condition of an equal luminosity and/or brightness and/or intensity with a tolerance of e.g. ±50% or less, preferably a tolerance of ±20% or less, more preferably a tolerance of ±5% or less. The bias light may be fed into a substrate of the longitudinal optical sensor, in particular a substrate of the sensor region. For example, the longitudinal optical sensor may comprise at least one optical waveguide, e.g. the sensor substrate. The longitudinal optical sensor may comprise at least one diffusor and/or at least one diffractive optical element and/or at least one beam homogenizer adapted to decouple the bias light from the optical waveguide.

The bias light beam may be a modulated light beam. As will be outlined in detail below, the detector may comprise at least one modulation device. The modulation device may be adapted to modulate the bias light beam. The detector may comprise at least one target light source adapted to generate at least one target light beam. As used herein, the term “target light source” refers to an illumination source adapted for generation of the target light beam, in particular for illumination of the object and/or gas. The modulation device may be adapted to modulate the target light beam. The modulation device may be adapted to modulate the target light beam and the bias light beam with different frequencies. The bias light source may be embodied as a pulsed illumination source, for example as a pulsed laser. The bias light source may be a pulsed light source.

The bias light source may be adapted to weakly illuminate the sensor region. As used herein, the term “weakly illuminated”, refers to a weak absorption behavior of the sensor region with respect to the bias light beam. In particular, the wavelength of the bias light beam may be different from a wavelength of an absorption maximum of the material of the sensor region such that the bias light beam may be weakly absorbed by the sensor region. The bias light source may be adapted to illuminate the sensor region with the bias light beam having a wavelength deviating from a wavelength at an absorption maxima of the sensor region. For example, the longitudinal optical sensor may be adapted to absorb 10% of the bias light beam, preferably 1% of the bias light beam and more preferably 0.1% of the bias light beam. However, other embodiments are feasible.

The bias light source may be adapted to illuminate the sensor region such that the longitudinal optical sensor has an immediate and/or a short response behavior. As used herein, the term “immediate and/or short response behavior” refers to a response behavior shorter than 0.1 seconds. As outlined above, optical sensors comprising semiconducting materials, for example amorphous silicon, hydrogenated amorphous silicon, hydrogenated microcrystalline silicon, hydrogenated amorphous silicon carbon alloy or hydrogenated amorphous germanium silicon alloy, show a long term temporal response behavior over several seconds. For example, this behavior can be observed in case the detector is illuminated after a long period of darkness. Without wishing to be bound by theory, this behavior may be caused by charging of deep trap states of the semiconductor, for example of a-Si:H. The trap sites may have charge carrier trapping lifetimes of seconds and may be located deeply within the bandgap. However, for several applications and purposes immediate or short response behavior is needed. The bias light beam may be adapted to illuminate the sensor region such that the deep trap states are occupied, resulting in immediate and/or a short response behavior. The bias light may further be used to modify the sensor signal in a controlled way such as to switch between different measurement modes or to increase or decrease the sensor response time or the sensor signal. Without wishing to be bound by theory, this may be achieved by modifying the number of available trap states or trap state types by modifying the brightness, wavelength, modulation or operation mode of the bias light source. As an example, the bias light source may be switched on or switched to a brighter mode to increase the total sensor signal, and switched off or switched to a darker mode, to obtain a higher signal to noise value.

The longitudinal optical sensor may be at least partially transparent for the bias light beam. The detector may comprise a stack of longitudinal optical sensors and the bias light source may be adapted to illuminate a stack of several longitudinal optical sensors, e.g. a stack of several a-Si:H-cells. Each of the longitudinal optical sensors may be transparent to the bias light beam. In particular, each of the longitudinal optical sensors may be transparent to the bias light beam having a wavelength in the IR region. For example, even very thick a-Si:H layers, which absorb almost the target light beam, may be transparent for the bias light beam having a wavelength in the IR region. As used herein, the term “at least partially transparent” may both refer to the option that the entire longitudinal optical sensor is transparent or a part (such as a sensitive region) of the longitudinal optical sensor is transparent and/or to the option that the longitudinal optical sensor or at least a transparent part of the longitudinal optical sensor may transmit the bias light beam in an attenuated or non-attenuated fashion. Thus, as an example, the transparent longitudinal optical sensor may have a transparency of at least 10%, preferably at least 20%, at least 40%, at least 50% or at least 70%. The longitudinal optical sensor may be designed such that the bias light beam may be weakly absorbed by the sensor region which results in a homogenous absorption through the whole layer stack.

Furthermore, the longitudinal optical sensor may be at least partially transparent with respect to the target light beam. Thus, generally, the longitudinal optical sensor may comprise at least one at least partially transparent optical sensor such that the target light beam at least partially may pass through the longitudinal optical sensor. In order to provide a sensory effect, generally, the longitudinal optical sensor typically has to provide some sort of interaction between the target light beam and the longitudinal optical sensor which typically results in a loss of transparency. The transparency of the longitudinal optical sensor may be dependent on a wavelength of the light beam, resulting in a spectral profile of a sensitivity, an absorption or a transparency of the longitudinal optical sensor. In case a plurality of longitudinal optical sensors is provided, such as a stack of longitudinal optical sensors, preferably all longitudinal optical sensors of the plurality and/or the stack are transparent.

The longitudinal optical sensor may be adapted to generate the at least one longitudinal sensor signal without contribution of the at least one bias light beam. The bias light beam, in particular the bias light beam having a wavelength in the IR region, may be adapted to illuminate the sensor region such that the trap levels are activated. The bias light beam, in particular the bias light beam having a wavelength in the IR region, may be adapted to illuminate the sensor region such that no charge carriers are generated which get extracted. Thus, the longitudinal signal may be generated without contributions caused by the illumination of the bias light, such as additional DC current, and without additional noise.

The at least one longitudinal optical sensor may comprise a sensor stack of longitudinal optical sensors. The sensor stack may be composed of longitudinal optical sensors being arranged such that the sensor regions of the longitudinal optical sensors are oriented essentially perpendicular to an optical axis of the detector. In case a plurality of longitudinal optical sensors is comprised, e. g. a stack of longitudinal optical sensors, the longitudinal optical sensors may be identical or may be different such that at least two different types of optical sensors may be comprised. For potential embodiments of the longitudinal optical sensor, reference may be made to the optical sensor as disclosed in WO 2012/110924 A1 and in WO 2016/120392 A1. As outlined above, in case a plurality of longitudinal optical sensors is provided, the spectral properties of the optical sensors not necessarily have to be identical. Thus, one of the longitudinal optical sensors may provide a strong absorption (such as absorption peak) in the red spectral region, another one of the longitudinal optical sensors may provide a strong absorption in the green spectral region, and another one may provide a strong absorption in the blue spectral region. Other embodiments are feasible.

In a particular embodiment of the present invention, the detector may comprise at least two individual longitudinal optical sensors, wherein each longitudinal optical sensor may be adapted to generate at least one longitudinal sensor signal. As an example, the sensor regions or the sensor surfaces of the longitudinal optical sensors may, thus, be oriented in parallel, wherein slight angular tolerances might be tolerable, such as angular tolerances of no more than 10°, preferably of no more than 5°. Herein, preferably all of the longitudinal optical sensors of the detector, which may, preferably, be arranged in form of a stack along the optical axis of the detector, may be transparent. Thus, the light beam may pass through a first transparent longitudinal optical sensor before impinging on the other longitudinal optical sensors, preferably subsequently. Thus, the target light beammay subsequently reach all longitudinal optical sensors present in the optical detector. Herein, the different longitudinal optical sensors may exhibit the same or different spectral sensitivities with respect to the incident light beam.

Preferably, the detector according to the present invention may comprise a stack of longitudinal optical sensors as disclosed in WO 2014/097181 A1, particularly in combination with one or more transversal optical sensors. As an example, one or more transversal optical sensors may be located on a side of the stack of longitudinal optical sensors facing towards the object. Alternatively or additionally, one or more transversal optical sensors may be located on a side of the stack of longitudinal optical sensors facing away from the object. Again, additionally or alternatively, one or more transversal optical sensors may be interposed in between the longitudinal optical sensors of the stack. However, embodiments which may only comprise a single longitudinal optical sensor but no transversal optical sensor may still be possible, such as in a case wherein only determining the depth of the object may be desired.

The detector further may comprise at least one transversal optical sensor. The transversal optical sensor may be adapted to determine a transversal position of the target light beam traveling from the object to the detector. The transversal position may be a position in at least one dimension perpendicular an optical axis of the detector. The transversal optical sensor may be adapted to generate at least one transversal sensor signal, wherein the evaluation device may be further designed to generate at least one item of information on a transversal position of the object by evaluating the transversal sensor signal. As used herein, the term “transversal optical sensor” generally refers to a device which is adapted to determine a transversal position of at least one light beam traveling from the object to the detector. With regard to the term position, reference may be made to the definition above. Thus, preferably, the transversal position may be or may comprise at least one coordinate in at least one dimension perpendicular to an optical axis of the detector. As an example, the transversal position may be a position of a light spot generated by the light beam in a plane perpendicular to the optical axis, such as on a light-sensitive sensor surface of the transversal optical sensor. As an example, the position in the plane may be given in Cartesian coordinates and/or polar coordinates. Other embodiments are feasible. For potential embodiments of the transversal optical sensor, reference may be made to WO 2014/097181 A1 or to WO2016/120392 A1. However, other embodiments are feasible and will be outlined in further detail below.

The transversal optical sensor may provide at least one transversal sensor signal. Herein, the transversal sensor signal may generally be an arbitrary signal indicative of the transversal position. As an example, the transversal sensor signal may be or may comprise a digital and/or an analog signal. As an example, the transversal sensor signal may be or may comprise a voltage signal and/or a current signal. Additionally or alternatively, the transversal sensor signal may be or may comprise digital data. The transversal sensor signal may comprise a single signal value and/or a series of signal values. The transversal sensor signal may further comprise an arbitrary signal which may be derived by combining two or more individual signals, such as by averaging two or more signals and/or by forming a quotient of two or more signals.

In a first embodiment similar to the disclosure according to WO 2014/097181 A1, the transversal optical sensor may be a photo detector having at least one first electrode, at least one second electrode and at least one photovoltaic material, wherein the photovoltaic material may be embedded in between the first electrode and the second electrode. Thus, the transversal optical sensor may be or may comprise one or more photo detectors, such as one or more organic photodetectors and, most preferably, one or more dye-sensitized organic solar cells (DSCs, also referred to as dye solar cells), such as one or more solid dye-sensitized organic solar cells (s-DSCs). Thus, the detector may comprise one or more DSCs (such as one or more sDSCs) acting as the at least one transversal optical sensor and one or more DSCs (such as one or more sDSCs) acting as the at least one longitudinal optical sensor.

In a further embodiment, the transversal optical sensor may comprise a layer of the photoconductive material, preferably an inorganic photoconductive material, such as one of the photoconductive materials as disclosed in WO2016/120392 A1. Herein, the layer of the photoconductive material may comprise a composition selected from a homogeneous, a crystalline, a polycrystalline, a microcrystalline, a nanocrystalline and/or an amorphous phase. Preferably, the layer of the photoconductive material may be embedded in between two layers of a transparent conducting oxide, preferably comprising indium tin oxide (ITO), fluorine doped tin oxide (FTO), or magnesium oxide (MgO), wherein one of the two layers may be replaced by metal nanowires, in particular by Ag nanowires. However, other material may be feasible, in particular according to the desired transparent spectral range.

As outlined above, the at least one longitudinal sensor signal, given the same total power of the illumination by the target light beam, is, according to the FiP effect, dependent on a beam cross-section of the light beam in the sensor region of the at least one longitudinal optical sensor. As used herein, the term ”beam cross-section” generally refers to a lateral extension of the light beam or a light spot generated by the light beam at a specific location. In case a circular light spot is generated, a radius, a diameter or a Gaussian beam waist or twice the Gaussian beam waist may function as a measure of the beam cross-section. In case non-circular light-spots are generated, the cross-section may be determined in any other feasible way, such as by determining the cross-section of a circle having the same area as the non-circular light spot, which is also referred to as the equivalent beam cross-section. Within this regard, it may be possible to employ the observation of an extremum, i.e. a maximum or a minimum, of the longitudinal sensor signal, in particular a global extremum, under a condition in which the corresponding material, such as a photovoltaic material, may be impinged by a light beam with the smallest possible cross-section, such as when the material may be located at or near a focal point as affected by an optical lens. In case the extremum is a maximum, this observation may be denominated as the positive FiP effect, while in case the extremum is a minimum, this observation may be denominated as the negative FiP effect.

Thus, in an embodiment, wherein the detector comprises the at least one stack of longitudinal optical sensors, irrespective of the material actually comprised in the sensor region but given the same total power of the illumination of the sensor region by the light beam, a light beam having a first beam diameter or beam cross-section may generate a first longitudinal sensor signal, whereas a light beam having a second beam diameter or beam-cross section being different from the first beam diameter or beam cross-section generates a second longitudinal sensor signal being different from the first longitudinal sensor signal. Thus, by comparing the longitudinal sensor signals, at least one item of information on the beam cross-section, specifically on the beam diameter, may be generated. For details of this effect, reference may be made to WO 2012/110924 A1. Accordingly, the longitudinal sensor signals generated by the longitudinal optical sensors may be compared, in order to gain information on the total power and/or intensity of the light beam and/or in order to normalize the longitudinal sensor signals and/or the at least one item of information on the longitudinal position of the object for the total power and/or total intensity of the light beam. Thus, as an example, a maximum value of the longitudinal optical sensor signals may be detected, and all longitudinal sensor signals may be divided by this maximum value, thereby generating normalized longitudinal optical sensor signals, which, then, may be transformed by using the above-mentioned known relationship, into the at least one item of longitudinal information on the object. Other ways of normalization are feasible, such as a normalization using a mean value of the longitudinal sensor signals and dividing all longitudinal sensor signals by the mean value. Other options are possible. Each of these options may be appropriate to render the transformation independent from the total power and/or intensity of the light beam. In addition, information on the total power and/or intensity of the light beam might, thus, be generated.

Specifically in case one or more beam properties of the light beam propagating from the object to the detector are known, the at least one item of information on the longitudinal position of the object may thus be derived from a known relationship between the at least one longitudinal sensor signal and a longitudinal position of the object. The known relationship may be stored in the evaluation device as an algorithm and/or as one or more calibration curves. As an example, specifically for Gaussian beams, a relationship between a beam diameter or beam waist and a position of the object may easily be derived by using the Gaussian relationship between the beam waist and a longitudinal coordinate.

This embodiment may, particularly, be used by the evaluation device in order to resolve an ambiguity in the known relationship between a beam cross-section of the light beam and the longitudinal position of the object. Thus, even if the beam properties of the light beam propagating from the object to the detector are known fully or partially, it is known that, in many beams, the beam cross-section narrows before reaching a focal point and, afterwards, widens again. Thus, before and after the focal point in which the light beam has the narrowest beam cross-section, positions along the axis of propagation of the light beam may occur in which the light beam has the same cross-section. Thus, as an example, at a distance z0 before and after the focal point, the cross-section of the light beam is identical. Thus, in case only one longitudinal optical sensor with a specific spectral sensitivity is used, a specific cross-section of the light beam might be determined, in case the overall power or intensity of the light beam is known. By using this information, the distance z0 of the respective longitudinal optical sensor from the focal point might be determined. However, in order to determine whether the respective longitudinal optical sensor is located before or behind the focal point, additional information is required, such as a history of movement of the object and/or the detector and/or information on whether the detector is located before or behind the focal point. In typical situations, this additional information may not be provided. Therefore, additional information may be gained in order to resolve the above-mentioned ambiguity. Thus, in case the evaluation device, by evaluating the longitudinal sensor signals, recognizes that the beam cross-section of the light beam on a first longitudinal optical sensor is larger than the beam cross-section of the light beam on a second longitudinal optical sensor, wherein the second longitudinal optical sensor is located behind the first longitudinal optical sensor, the evaluation device may determine that the light beam is still narrowing and that the location of the first longitudinal optical sensor is situated before the focal point of the light beam. Contrarily, in case the beam cross-section of the light beam on the first longitudinal optical sensor is smaller than the beam cross-section of the light beam on the second longitudinal optical sensor, the evaluation device may determine that the light beam is widening and that the location of the second longitudinal optical sensor is situated behind the focal point. Thus, generally, the evaluation device may be adapted to recognize whether the light beam widens or narrows, by comparing the longitudinal sensor signals of different longitudinal sensors.

For further details with regard to determining the at least one item of information on the longitudinal position of the object by employing the evaluation device according to the present invention, reference may made to the description in WO 2014/097181 A1. Thus, generally, the evaluation device may be adapted to compare the beam cross-section and/or the diameter of the light beam with known beam properties of the light beam in order to determine the at least one item of information on the longitudinal position of the object, preferably from a known dependency of a beam diameter of the light beam on at least one propagation coordinate in a direction of propagation of the light beam and/or from a known Gaussian profile of the light beam.

In addition to the at least one longitudinal coordinate of the object, at least one transversal coordinate of the object may be determined. Thus, generally, the evaluation device may further be adapted to determine at least one transversal coordinate of the object by determining a position of the light beam on the at least one transversal optical sensor, which may be a pixelated, a segmented or a large-area transversal optical sensor, as further outlined also in WO 2014/097181 A1.

In addition, the detector may comprise at least one transfer device, such as an optical lens, in particular one or more refractive lenses, particularly converging thin refractive lenses, such as convex or biconvex thin lenses, and/or one or more convex mirrors, which may further be arranged along the common optical axis. Most preferably, the light beam which emerges from the object may in this case travel first through the at least one transfer device and thereafter through the single transparent longitudinal optical sensor or the stack of the transparent longitudinal optical sensors until it may finally impinge on an imaging device. As used herein, the term “transfer device” refers to an optical element which may be configured to transfer the at least one light beam emerging from the object to optical sensors within the detector, i.e. the at least two longitudinal optical sensors and the at least one optional transversal optical sensor. Thus, the transfer device can be designed to feed light propagating from the object to the detector to the optical sensors, wherein 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 transversal and/or longitudinal optical sensor.

In addition, the at least one transfer device may have imaging properties. Consequently, the transfer device comprises at least one imaging element, for example at least one lens and/or at least one curved mirror, since, in the case of such imaging elements, for example, a geometry of the illumination on the sensor region can be dependent on a relative positioning, for example a distance, between the transfer device and the object. As used herein, the transfer device may be designed in such a way that the electromagnetic radiation which emerges from the object is transferred completely to the sensor region, for example is focused completely onto the sensor region, in particular if the object is arranged in a visual range of the detector.

Generally, the detector may further comprise at least one imaging device, i.e. a device capable of acquiring at least one image. The imaging device can be embodied in various ways. Thus, the imaging device can be for example part of the detector in a detector housing. Alternatively or additionally, however, the imaging device can also be arranged outside the detector housing, for example as a separate imaging device. Alternatively or additionally, the imaging device can also be connected to the detector or even be part of the detector. In a preferred arrangement, the stack of the transparent longitudinal optical sensors and the imaging device are aligned along a common optical axis along which the light beam travels. Thus, it may be possible to locate an imaging device in the optical path of the light beam in a manner that the light beam travels through the stack of the transparent longitudinal optical sensors until it impinges on the imaging device. However, other arrangements are possible.

As used herein, an “imaging device” is generally understood as a device which can generate a one-dimensional, a two-dimensional, or a three-dimensional image of the object or of a part thereof. In particular, the detector, with or without the at least one optional imaging device, can be completely or partly used as a camera, such as an IR camera, or an RGB camera, i.e. a camera which is designed to deliver three basic colors which are designated as red, green, and blue, on three separate connections. Thus, as an example, the at least one imaging device may be or may comprise at least one imaging device selected from the group consisting of: a pixelated organic camera element, preferably a pixelated organic camera chip; a pixelated inorganic camera element, preferably a pixelated inorganic camera chip, more preferably a CCD- or CMOS-chip; a monochrome camera element, preferably a monochrome camera chip; a multicolor camera element, preferably a multicolor camera chip; a full-color camera element, preferably a full-color camera chip. The imaging device may be or may comprise at least one device selected from the group consisting of a monochrome imaging device, a multi-chrome imaging device and at least one full color imaging device. A multi-chrome imaging device and/or a full color imaging device may be generated by using filter techniques and/or by using intrinsic color sensitivity or other techniques, as the skilled person will recognize. Other embodiments of the imaging device are also possible.

The imaging device may be designed to image a plurality of partial regions of the object successively and/or simultaneously. By way of example, a partial region of the object can be a one-dimensional, a two-dimensional, or a three-dimensional region of the object which is delimited for example by a resolution limit of the imaging device and from which electromagnetic radiation emerges. In this context, imaging should be understood to mean that the electromagnetic radiation which emerges from the respective partial region of the object is fed into the imaging device, for example by means of the at least one optional transfer device of the detector. The electromagnetic rays can be generated by the object itself, for example in the form of a luminescent radiation. Alternatively or additionally, the at least one detector may comprise at least one illumination source for illuminating the object.

In particular, the imaging device can be designed to image sequentially, for example by means of a scanning method, in particular using at least one row scan and/or line scan, the plurality of partial regions sequentially. However, other embodiments are also possible, for example embodiments in which a plurality of partial regions is simultaneously imaged. The imaging device is designed to generate, during this imaging of the partial regions of the object, signals, preferably electronic signals, associated with the partial regions. The signal may be an analogue and/or a digital signal. By way of example, an electronic signal can be associated with each partial region. The electronic signals can accordingly be generated simultaneously or else in a temporally staggered manner. By way of example, during a row scan or line scan, it is possible to generate a sequence of electronic signals which correspond to the partial regions of the object, which are strung together in a line, for example. Further, the imaging device may comprise one or more signal processing devices, such as one or more filters and/or analogue-digital-converters for processing and/or preprocessing the electronic signals.

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 optical sensors. The latter case can be affected for example by at least one illumination source being used. The illumination source can be embodied in various ways. Thus, the illumination source can be for example part of the detector in a detector housing. Alternatively or additionally, however, the at least one illumination source can also be arranged outside a detector housing, for example as a separate light source. The illumination source can be arranged separately from the object and illuminate the object from a distance. Alternatively or additionally, the illumination source can also be connected to the object or even be part of the object, such that, by way of example, the electromagnetic radiation emerging from the object can also be generated directly by the illumination source. By way of example, at least one illumination source can be arranged on and/or in the object and directly generate the electromagnetic radiation by means of which the sensor region is illuminated. This illumination source can for example be or comprise an ambient light source and/or may be or may comprise an artificial illumination source. By way of example, at least one infrared emitter and/or at least one emitter for visible light and/or at least one emitter for ultraviolet light can be arranged on the object. By way of example, at least one light emitting diode and/or at least one laser diode can be arranged on and/or in the object. The illumination source can comprise in particular one or a plurality of the following illumination sources: a laser, in particular a laser diode, although in principle, alternatively or additionally, other types of lasers can also be used; a light emitting diode; an incandescent lamp; a neon light; a flame source; a heat source; an organic light source, in particular an organic light emitting diode; a structured light source. Alternatively or additionally, other illumination sources can also be used. It is particularly preferred if the illumination source is designed to generate one or more light beams having a Gaussian beam profile, as is at least approximately the case for example in many lasers. For further potential embodiments of the optional illumination source, reference may be made to one of WO 2012/110924 A1 and WO 2014/097181 A1. Still, other embodiments are feasible.

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. Most preferably, 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. Herein, it is particularly preferred when the illumination source may exhibit a spectral range which may be related to the spectral sensitivities of the longitudinal sensors, particularly in a manner to ensure that the longitudinal sensor which may be illuminated by the respective illumination source may provide a sensor signal with a high intensity which may, thus, enable a high-resolution evaluation with a sufficient signal-to-noise-ratio.

Furthermore, the detector can have at least one modulation device for modulating the illumination of the object, in particular for a periodic modulation, in particular a periodic beam interrupting device. A modulation of the illumination should be understood to mean a process in which a total power of the illumination is varied, preferably periodically, in particular with one or a plurality of modulation frequencies. In particular, a periodic modulation can be effected between a maximum value and a minimum value of the total power of the illumination. The minimum value can be 0, but can also be > 0, such that, by way of example, complete modulation does not have to be effected. The modulation can be effected for example in a beam path between the object and the optical sensor, for example by the at least one modulation device being arranged in said beam path. Alternatively or additionally, however, the modulation can also be effected in a beam path between an optional illumination source - described in even greater detail below - for illuminating the object and the object, for example by the at least one modulation device being arranged in said beam path. A combination of these possibilities is also conceivable. The at least one modulation device can comprise for example 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. Alternatively or additionally, however, it is also possible to use one or a plurality of different types of modulation devices, for example modulation devices based on an electro-optical effect and/or an acousto-optical effect. Once again alternatively or additionally, the at least one optional illumination source itself can also be designed to generate a modulated illumination, for example by said illumination source itself having a modulated intensity and/or total power, for example a periodically modulated total power, and/or by said illumination source being embodied as a pulsed illumination source, for example as a pulsed laser. Thus, by way of example, the at least one modulation device can also be wholly or partly integrated into the illumination source. Various possibilities are conceivable.

Accordingly, the detector can be designed in particular to detect at least two longitudinal sensor signals in the case of different modulations, in particular at least two longitudinal sensor signals at respectively different modulation frequencies. The evaluation device can be designed to generate the geometrical information from the at least two longitudinal sensor signals. As described in WO 2012/110924 A1 and WO 2014/097181 A1, it is possible to resolve ambiguities and/or it is possible to take account of the fact that, for example, a total power of the illumination is generally unknown. By way of example, the detector can be designed to bring about a modulation of the illumination of the object and/or at least one sensor region of the detector, such as at least one sensor region of the at least one longitudinal optical sensor, with a frequency of 0.05 Hz to 1 MHz, such as 0.1 Hz to 10 kHz. As outlined above, for this purpose, the detector may comprise at least one modulation device, which may be integrated into the at least one optional illumination source and/or may be independent from the illumination source. Thus, at least one illumination source might, by itself, be adapted to generate the above-mentioned modulation of the illumination, and/or at least one independent modulation device may be present, such as at least one chopper and/or at least one device having a modulated transmissibility, such as at least one electro-optical device and/or at least one acousto-optical device.

According to the present invention, it may be advantageous in order to apply at least one modulation frequency to the optical detector as described above. However, it may still be possible to directly determine the longitudinal sensor signal without applying a modulation frequency to the optical detector. As will be demonstrated below in more detail, an application of a modulation frequency may not be required under many relevant circumstances in order to acquire the desired longitudinal information about the object. As a result, the optical detector may, thus, not be required to comprise a modulation device which may further contribute to the simple and cost-effective setup of the spatial detector. As a further result, a spatial light modulator may be used in a time-multiplexing mode rather than a frequency-multiplexing mode or in a combination thereof.

In a further aspect of the present invention, a detector system, in particular 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 of at least one detector according to one or more of the embodiments disclosed above or disclosed in further detail below. Thus, for optional embodiments of the method, reference might be made to the description of the various embodiments of the detector.

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. The detector system may comprise at least two beacon devices, wherein at least one property of a light beam emitted by a first beacon device may be different from at least one property of a light beam emitted by a second beacon device. The light beam of the first beacon device and the light beam of second beacon device may be emitted simultaneously or sequentially.

In a further aspect of the present invention, an arrangement comprising at least two individual detectors according to any one of the preceding embodiments, preferably two or three individual optical sensors, which may be placed at at least two distinct locations is proposed. Herein, the at least two detectors preferably may have identical optical properties but might also be different with respect from each other. In addition, the arrangement may further comprise at least one illumination source. Herein, the at least one object might be illuminated by using at least one illumination source which generates primary light, wherein the at least one object elastically or inelastically reflects the primary light, thereby generating a plurality of light beams which propagate to one of the at least two detectors. The at least one illumination source may form or may not form a constituent part of each of the at least two detectors. By way of example, the at least one illumination source itself may be or may comprise an ambient light source and/or may be or may comprise an artificial illumination source. This embodiment is preferably suited for an application in which at least two detectors, preferentially two identical detectors, are employed for acquiring depth information, in particular, for the purpose to providing a measurement volume which extends the inherent measurement volume of a single detector.

In this regard, the individual optical sensor may, preferably, be spaced apart from the other individual optical sensors comprised by the detector in order to allow acquiring an individual image which may differ from the images taken by the other individual optical sensors. In particular, the individual optical sensors may be arranged in separate beam paths in a collimated arrangement in order to generate a single circular, three-dimensional image. Thus, the individual optical sensors may be aligned in a manner that they are located parallel to the optical axis and may, in addition, exhibit an individual displacement in an orientation perpendicular to the optical axis of the detector. Herein, an alignment may be achieved by adequate measures, such as by adjusting a location and orientation of the individual optical sensor and/or the corresponding transfer element. Thus, the two individual optical sensors may, preferably, be spaced apart in a manner that they may be able to generate or increase a perception of depth information, especially in a fashion that the depth information may be obtained by combining visual information as derived from the two individual optical sensors having overlapping fields of view, such as the visual information as obtained by binocular vision. For this purpose, the individual optical sensors may, preferably be spaced apart from each other by a distance from 1 cm to 100 cm, preferably from 10 cm to 25 cm, as determined in the direction perpendicular to the optical axis. As used herein, the detector as provided in this embodiment may, in particular, be part of a “stereoscopic system” which will be described below in more detail. Besides allowing stereoscopic vision, further particular advantages of the stereoscopic system which are primarily based on a use of more than one optical sensor may, in particular, include an increase of the total intensity and/or a lower detection threshold.

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 proposed. The human-machine interface as proposed may make use of the fact that the above-mentioned detector in one or more of the embodiments mentioned above or as mentioned in further detail below may be used by one or more users for providing information and/or commands to a machine. Thus, preferably, the human-machine interface may be used for inputting control commands.

The human-machine interface comprises at least one detector 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 as disclosed in further detail below, wherein the human-machine interface is designed to generate at least one item of geometrical information of the user by means of the detector wherein the human-machine interface is designed to assign the geometrical information to at least one item of information, in particular to at least one control command.

In a further aspect of the present invention, an entertainment device for carrying out at least one entertainment function is disclosed. 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. Additionally or alternatively, the entertainment device may also be used for other purposes, such as for exercising, sports, physical therapy or motion tracking in general. 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.

In a further aspect of the present invention, a tracking system for tracking the position of at least one movable object is provided. As 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 or at least one part of an object. Additionally, the tracking system may be adapted to provide information on at least one predicted future position 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 comprise the at least one evaluation device and/or may be part of the at least one evaluation device and/or might 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 tracking system may comprise one, two or more detectors, particularly two or more identical detectors, which allow for a reliable acquisition of depth information about the at least one object in an overlapping volume between the two or more detectors. The track controller is adapted to track a series of positions of the object, each position comprising at least one item of information on a position of the object at a specific point in time.

The tracking system may further comprise at least one beacon device connectable to the object. For a potential definition of the beacon device, reference may be made to WO 2014/097181 A1. The tracking system preferably is adapted such that the detector may generate an information on the position of the object of the at least one beacon device, in particular to generate the information on the position of the object which comprises a specific beacon device exhibiting a specific spectral sensitivity. Thus, more than one beacon exhibiting a different spectral sensitivity may be tracked by the detector of the present invention, preferably in a simultaneous manner. Herein, the beacon device may fully or partially be embodied as an active beacon device and/or as a passive beacon device. As an example, the beacon device may comprise at least one illumination source adapted to generate at least one light beam to be transmitted to the detector. Additionally or alternatively, 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.

In a further aspect of the present invention, a scanning system for determining at least one position of at least one object is provided. As used herein, the scanning system is a device which is adapted to emit at least one light beam being configured for an illumination of at least one dot located at at least one surface of the at least one object and for generating at least one item of information about the distance between the at least one dot and the scanning system. For the purpose of generating the at least one item of information about the distance between the at least one dot and the scanning system, the scanning system comprises at least one of the detectors according to the present invention, such as at least one of the detectors as disclosed in one or more of the embodiments listed above and/or as disclosed in one or more of the embodiments below.

Thus, the scanning system comprises 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 a small area on a part of the surface of the object which may be selected, 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 determining 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. 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 comprising as magnetic material, in particular for increasing the accuracy of the distance measurement and/or the handleablity of the scanning system by the user.

In a particularly preferred embodiment, 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.

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.

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, 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. Thus, 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.

In a further aspect of the present invention, a stereoscopic system for generating at least one single circular, three-dimensional image of at least one object is provided. As used herein, the stereoscopic system as disclosed above and/or below may comprise at least two of the FiP sensors as the optical sensors, wherein a first FiP sensor may be comprised in a tracking system, in particular in a tracking system according to the present invention, while a second FiP sensor may be comprised in a scanning system, in particular in a scanning system according to the present invention. Herein, the FiP sensors may, preferably, be arranged in separate beam paths in a collimated arrangement, such as by aligning the FiP sensors parallel to the optical axis and individually displaced perpendicular to the optical axis of the stereoscopic system. Thus, the FiP sensors may be able to generate or increase a perception of depth information, especially, by obtaining the depth information by a combination of the visual information derived from the individual FiP sensors which have overlapping fields of view and are, preferably, sensitive to an individual modulation frequency. For this purpose, the individual FiP sensors may, preferably, be spaced apart from each other by a distance from 1 cm to 100 cm, preferably from 10 cm to 25 cm, as determined in the direction perpendicular to the optical axis. In this preferred embodiment, the tracking system may, thus, be employed for determining a position of a modulated active target while the scanning system which is adapted to project one or more dots onto the one or more surfaces of the one or more objects may be used for generating at least one item of information about the distance between the at least one dot and the scanning system. In addition, the stereoscopic system may further comprise a separate position sensitive device being adapted for generating the item of information on the transversal position of the at least one object within the image as described elsewhere in this application.

Besides allowing stereoscopic vision, further particular advantages of the stereoscopic system which are primarily based on a use of more than one optical sensor may, in particular, include an increase of the total intensity and/or a lower detection threshold. Further, whereas in a conventional stereoscopic system which comprises at least two conventional position sensitive devices corresponding pixels in the respective images have to be determined by applying considerable computational effort, in the stereoscopic system according to the present invention which comprises at least two FiP sensors the corresponding pixels in the respective images being recorded by using the FiP sensors, wherein each of the FiP sensors may be operated with a different modulation frequency, may apparently be assigned with respect to each other. Thus, it may be emphasized that the stereoscopic system according to the present invention may allow generating the at least one item of information on the longitudinal position of the object as well as on the transversal position of the object with reduced effort.

For further details of the stereoscopic system, reference may be made to the description of the tracking system and the scanning system, respectively.

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 the present invention, such as disclosed in one or more of the embodiments given above or given in further detail below. 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 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.

In a further aspect of the present invention, a method for optical detection, in particular for determining a position of at least one object, is disclosed. The method preferably may make use of at least one detector according to the present invention, such as of at least one detector according to one or more of the embodiments disclosed above or disclosed in further detail below. Thus, for optional embodiments of the method, reference might be made to the description of the various embodiments of the detector.

The method comprises the following steps, which may be performed in the given order or in a different order. Further, additional method steps might be provided which are not listed. Further, two or more or even all of the method steps might be performed simultaneously, at least partially. Further, two or more or even all of the method steps might be performed twice or even more than twice, repeatedly.

The method according to the present invention comprises the following steps:

- generating at least one sensor signal by using at least one optical sensor, wherein the sensor signal is dependent on an illumination of a sensor region of the optical sensor by an incident target light beam, wherein the sensor region comprises at least one semiconducting material;
- evaluating the sensor signal by using at least one evaluation device and generating at least one item of information on the target light beam; and
- generating at least one bias light beam by using at least one bias light source and at least partially illuminating the sensor region.

For further details concerning the method according to the present invention, reference may be made to the description of the optical detector as provided above and/or below.

In a further aspect of the present invention, a use of a detector according to the present invention is disclosed. Therein, a use of the detector for a purpose of determining a position of an object, in particular a lateral position of an object, is proposed, in particular, for a purpose of use selected from the group consisting of: a position measurement, in particular in traffic technology; an entertainment application; a security application; a human-machine interface application; a tracking application; a scanning application; a stereoscopic vision 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 position measurement of objects with a thermal signature (hotter or colder than background); a machine vision application; a robotic application.

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 cartography application; a mapping application for generating maps of at least one space; a homing or tracking beacon detector for vehicles; 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 surveillance application; an automotive application; a transport application; a logistics application; a vehicle application; an airplane application; a ship application; a spacecraft application; a robotic application; a medical application; a sports' application; a building application; a construction application; a manufacturing application; a machine vision application; a use in combination with at least one sensing technology selected from time-of-flight detector, radar, Lidar, ultrasonic sensors, or interferometry. 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.

Thus, firstly, 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. The devices according to the present invention are generally advantageous as compared to active detector systems, specifically since the devices according to the present invention avoid actively sending signals which may be detected by third parties, as is the case e.g. in radar applications, ultrasound applications, LIDAR or similar active detector devices. 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 front-lighting 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 which may, particularly, be adapted for anticipating maneuvers of the driver beforehand for collision avoidance. 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. Herein, the use of an airbag may, especially, be prevented in a case in which the passenger may be located within the vehicle in a manner that a use of the airbag might cause an injury, in particular a severe injury, with the passenger. 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 other drugs.

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 stereovision systems such as LIDAR. 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, 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 may generally 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 generally be used for vision, in particular for vision under difficult visibility conditions, such as in night vision, fog vision, or fume vision. For achieving this purpose, the detector may be sensitive at least within a wavelength range in which small particles, such as particles being present in smoke or fume, or small droplets, such as droplets being present in fog, mist or haze, may not reflect an incident light beam or only a small partition thereof. As generally known, the reflection of the incident light beam may be small or negligent in a case in which the wavelength of the incident beam exceeds the size of the particles or of the droplets, respectively. Further, might vision may be enabled by detecting thermal radiation being emitted by a bodies and objects. Thus, the detector may particularly be sensitive within the infrared (IR) spectral range, preferably within the mid infrared (MidIR) spectral range, may, thus, allow good visibility even at night, in fume, smoke, fog, mist, or haze.

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 and/or no or a vanishing baseline with respect to a light source, may be used for capturing 3D information in medical devices such as in flexible and/or rigid endoscopes, such as for measuring lesion or tumor size or the like in diagnosis and/or follow-up, for measuring lumen, volumes or hollow spaces inside the body, for focus or autofocus of further instruments such as 2D cameras, for size calibration of endoscopic images or the like. 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.

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 or 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 mentioned 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 are generally useful and advantageous due to a low calculation power required, an instant response and due to a passive nature of the detection system which is, generally, 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 may, generally, 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 racquet, 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 may generally 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 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 vehicles capable of flight, such as drones or multicopters, in order to monitor buildings, chimneys, production sites, 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, to find or monitor one or more persons, animals, or moving objects, 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 cooling 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 cat litter robots, security robots that detect intruders, robotic lawn mowers, automated pool cleaners, rain gutter cleaning robots, window washing robots, toy robots, telepresence robots, social robots providing company to less mobile people, 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 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, 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. Herein, the devices according to the present invention may be used to support elderly or disabled persons, blind persons, or persons with limited vision abilities, 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 and/or acoustical signals adapted for 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. In this regard, determining a distance of an illuminated spot on a surface which may provide reflected or diffusely scattered light from the detector may be performed virtually independent of the distance of the light source from the illuminated spot. This property of the present invention is in direct contrast to known methods, such as triangulation or such as time-of-flight (TOF) methods, wherein the distance between the light source and the illuminated spot must be known a priori or calculated a posteriori in order to be able to determine the distance between the detector and the illuminated spot. In contrast hereto, for the detector according to the present invention is may be sufficient that the spot is adequately illuminated. Further, the devices according to the present invention may be used for scanning reflective surfaces, such of metal surfaces, independent whether they may comprise a solid or a liquid surface. 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.

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 a 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 devices according to the present invention may be combined with one or more other types of measurement devices. Thus, the devices according to the present invention may be combined with one or more other types of sensors or detectors, such as a time of flight (TOF) detector, a stereo camera, a lightfield camera, a lidar, a radar, a sonar, an ultrasonic detector, or interferometry. When combining devices according to the present invention with one or more other types of sensors or detectors, the devices according to the present invention and the at least one further sensor or detector may be designed as independent devices, with the devices according to the present invention being separate from the at least one further sensor or detector. Alternatively, the devices according to the present invention and the at least one further sensor or detector may fully or partially be integrated or designed as a single device.

Thus, as a non-limiting example, the devices according to the present invention may further comprise a stereo camera. As used herein, a stereo camera is a camera which is designed for capturing images of a scene or an object from at least two different perspectives. Thus, the devices according to the present invention may be combined with at least one stereo camera.

The stereo camera’s functionality is generally known in the art, since stereo cameras generally are known to the skilled person. The combination with the devices according to the present invention may provide additional distance information. Thus, the devices according to the present invention may be adapted, in addition to the stereo camera’s information, to provide at least one item of information on a longitudinal position of at least one object within a scene captured by the stereo camera. Information provided by the stereo camera, such as distance information obtained by evaluating triangulation measurements performed by using the stereo camera, may be calibrated and/or validated by using the devices according to the present invention. Thus, as an example, the stereo camera may be used to provide at least one first item of information on the longitudinal position of the at least one object, such as by using triangulation measurements, and the devices according to the present invention may be used to provide at least one second item of information on the longitudinal position of the at least one object. The first item of information and the second item of information may be used to improve accuracy of the measurements. Thus, the first item of information may be used for calibrating the second item of information or vice a versa. Consequently, the devices according to the present invention, as an example, may form a stereo camera system, having the stereo camera and the devices according to the present invention, wherein the stereo camera system is adapted to calibrate the information provided by the stereo camera by using the information provided by devices according to the present invention.

Consequently, additionally or alternatively, the devices according to the present invention may be adapted to use the second item of information, provided by the devices according to the present invention, for correcting the first item of information, provided by the stereo camera. Additionally or alternatively, the devices according to the present invention may be adapted to use the second item of information, provided by the devices according to the present invention, for correcting optical distortion of the stereo camera. Further, the devices according to the present invention may adapted to calculate stereo information provided by the stereo camera, and the second item of information provided by devices according to the present invention may be used for speeding up the calculation of the stereo information.

As an example, the devices according to the present invention may be adapted to use at least one virtual or real object within a scene captured by the devices according to the present invention for calibrating the stereo camera. As an example, one or more objects and/or areas and/or spots may be used for calibration. As an example, the distance of at least one object or spot may be determined by using the devices according to the present invention, and distance information provided by the stereo camera may be calibrated by using this distance is determined by using the devices according to the present invention. For instance, at least one active light spot of the devices according to the present invention may be used as a calibration point for the stereo camera. The active light spot, as an example, may move freely in the picture.

The devices according to the present invention may be adapted to continuously or discontinuously calibrate the stereo camera by using information provided by the active distance sensor. Thus, as an example, the calibration may take place at regular intervals, continuously or occasionally.

Further, typical stereo cameras exhibit measurement errors or uncertainties which are dependent on the distance of the object. This measurement error may be reduced when combined with information provided by the devices according to the present invention.

Combinations of stereo cameras with other types of distance sensors are generally known in the art. Thus, in D. Scaramuzza et al., IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2007, pp. 4164-4169, 2007, an extrinsic self-calibration of a camera and a 3D laser range finder from natural scenes is disclosed. Similarly, in D. Klimentjew et al., IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI), pages 236-241, 2010, a multi sensor fusion of camera and 3D laser range finder for object recognition is disclosed. As the skilled person will recognize, the laser range finder in these setups known in the art may simply be replaced or complemented by at least one device according to the present invention, without altering the methods and advantages disclosed by these prior art documents. For potential setups of the stereo camera, reference may be made to these prior art documents. Still, other setups and embodiments of the at least one optional stereo camera are feasible.

Preferably, for further potential details of the optical detector, the method, the human-machine interface, the entertainment device, the tracking system, the camera and the various uses of the detector, in particular with regard to the transfer device, the transversal optical sensors, the evaluation device and, if applicable, to the longitudinal optical sensor, the modulation device, the illumination source and the imaging device, specifically with respect to the potential materials, setups and further details, reference may be made to one or more of WO 2012/110924 A1, US 2012/206336 A1, WO 2014/097181 A1, US 2014/291480 A1, and WO 2016/120392 A1, the full content of all of which is herewith included by reference.

The above-described detector, the method, the human-machine interface and the entertainment device and also the proposed uses have considerable advantages over the prior art. Thus, generally, a simple and, still, efficient detector for an accurate determining a position of at least one object in space may be provided. Therein, as an example, three-dimensional coordinates of an object or a part thereof may be determined in a fast and efficient way.

As compared to devices known in the art, the detector as proposed provides a high degree of simplicity, specifically with regard to an optical setup of the detector. Thus, in principle, a simple combination of a material for the sensor region in combination with a variation of the cross-section of an incident light beam impinging on this material in the sensor region in conjunction with an appropriate evaluation device is sufficient for reliable high precision position detection. This high degree of simplicity, in combination with the possibility of high precision measurements, is specifically suited for machine control, such as in human-machine interfaces and, more preferably, in gaming, tracking, scanning, and a stereoscopic vision. Thus, cost-efficient entertainment devices may be provided which may be used for a large number of gaming, entertaining, tracking, scanning, and stereoscopic vision purposes.

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

Embodiment 1: A detector for an optical detection, comprising:

- at least one optical sensor, the optical sensor has at least one sensor region for an incident target light beam, wherein the sensor region is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region by the target light beam, wherein the sensor region comprises at least one semiconducting material;
- at least one evaluation device, wherein the evaluation device is designed to generate at least one item of information of the target light beam by evaluating the sensor signal; and
- at least one bias light source, wherein the bias light source is designed to generate at least one bias light beam for at least partially illuminating the sensor region.

Embodiment 2: The detector according to the preceding embodiment, wherein the bias light source is adapted to uniformly illuminate the sensor region.

Embodiment 3: The detector according to any one of the preceding embodiments, wherein the bias light source is adapted to weakly illuminate the sensor region.

Embodiment 4: The detector according to any one of the preceding embodiments, wherein the bias light source is adapted to generate a long wavelength illumination.

Embodiment 5: The detector according to any one of the preceding embodiments, wherein the bias light source comprises at least one infrared light source, wherein the bias light beam has a wavelength in the infrared spectral range.

Embodiment 6: The detector according to any one of the preceding embodiments, wherein the bias light source is designed to generate the at least one bias light beam for illuminating the whole sensor region.

Embodiment 7: The detector according to any one of the preceding embodiments, wherein the detector comprises at least one modulation device adapted to modulate the bias light beam.

Embodiment 8: The detector according to the preceding embodiment, wherein the detector comprises at least one target light source adapted to generate the at least one target light beam, wherein the modulation device is adapted to modulate the target light beam, wherein the modulation device is adapted to modulate the target light beam and the bias light beam with different frequencies.

Embodiment 9: The detector according to any one of the two preceding embodiments, wherein the bias light source is a pulsed light source.

Embodiment 10: The detector according to any one of the preceding embodiments, wherein the bias light source is adapted to illuminate the sensor region such that the optical sensor has an immediate and/or a short response behavior.

Embodiment 11: The detector according to any one of the preceding embodiments, wherein the optical sensor is adapted to generate the at least one longitudinal sensor signal without contribution of the at least one bias light beam.

Embodiment 12: The detector according to any one of the preceding embodiments, wherein the semiconductor material comprises a material selected from the group consisting of: amorphous silicon (a-Si); an alloy comprising amorphous silicon; hydrogenated amorphous silicon (a-Si:H); microcrystalline silicon (µc-Si); hydrogenated microcrystalline silicon (µc-Si:H); hydrogenated amorphous silicon carbon alloy (a-SiC:H), hydrogenated amorphous germanium silicon alloy (a-GeSi:H); microcrystalline CIGS, microcrystalline CIS; microcrystalline CZTS; microcrystalline CdTe; crystalline silicon (c-Si); crystalline germanium (c-Ge); crystalline Silicon Germanium alloy (c-SiGe); extrinsic silicon; extrinsic germanium; InGaAs; extended InGaAs; InAs; InSb; GaP; GaN; SiC; organic semiconductors; a semiconductive metal oxid, in particular a n-conductive semiconductive metal oxid, for example titanium dioxide (TiO_2), in particular dye sensitized titanium dioxide (TiO_2).

Embodiment 13: The detector according to any one of the preceding embodiments, wherein the optical sensor is at least partially transparent for the bias light beam.

Embodiment 14: The detector according to any one of the preceding embodiments, wherein the optical sensor is a longitudinal optical sensor, wherein the sensor region is designed to generate at least one longitudinal sensor signal in a manner dependent on an illumination of the sensor region by the light beam, wherein the longitudinal sensor signal, given the same total power of the illumination, is dependent on a beam cross-section of the light beam in the sensor region.

Embodiment 15: The detector according to the preceding embodiment, wherein the evaluation device is designed to generate at least one item of information on a longitudinal position of an object by evaluating the longitudinal sensor signal.

Embodiment 16: The detector according to any one of the two preceding embodiments, wherein the detector comprises at least one stack of longitudinal optical sensors.

Embodiment 17: The detector according to any one of the preceding embodiments, further comprising at least one transversal optical sensor, the transversal optical sensor being adapted to determine a transversal position of target the light beam traveling from the object to the detector, the transversal position being a position in at least one dimension perpendicular an optical axis of the detector, the transversal optical sensor being adapted to generate at least one transversal sensor signal, wherein the evaluation device is further designed to generate at least one item of information on a transversal position of the object by evaluating the transversal sensor signal.

Embodiment 18: The detector according to any one of the preceding embodiments, wherein the detector comprises at least one transfer device, such as an optical lens, in particular one or more refractive lenses, particularly converging thin refractive lenses, such as convex or biconvex thin lenses, and/or one or more convex mirrors, which further are arranged along a common optical axis.

Embodiment 19: The detector according to any one of the preceding embodiments, wherein the detector comprises at least one imaging device.

Embodiment 20: 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 21: The detector system according to the preceding embodiment, wherein the detector system comprises at least two beacon devices, wherein at least one property of a light beam emitted by a first beacon device is different from at least one property of a light beam emitted by a second beacon device.

Embodiment 22: The detector system according to the any one of the two preceding embodiments, wherein the light beam of the first beacon device and the light beam of second beacon device are emitted simultaneously or sequentially.

Embodiment 23: A method for an optical detection, in particular using a detector according to any of the preceding embodiments relating to a detector, comprising the following steps:

- generating at least one sensor signal by using at least one optical sensor, wherein the sensor signal is dependent on an illumination of a sensor region of the optical sensor by a target light beam, wherein the sensor region comprises at least one semiconducting material;
- evaluating the sensor signal by using at least one evaluation device and generating at least one item of information on the target light beam; and
- generating at least one bias light beam by using at least one bias light source and at least partially illuminating the sensor region.

Embodiment 24: 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 25: 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 according to any one of the preceding embodiments relating to a detector, wherein the human-machine interface is designed to generate at least one item of geometrical information of the user by means of the detector wherein the human-machine interface is designed to assign to the geometrical information at least one item of information.

Embodiment 26: The human-machine interface according to the preceding embodiment, wherein the at least one item of geometrical information of the user is selected from the group consisting of: a position of a body of the user; a position of at least one body part of the user; an orientation of a body of the user; an orientation of at least one body part of the user.

Embodiment 27: The human-machine interface according to any of the two preceding embodiments, wherein the human-machine interface further comprises at least one beacon device connectable to the user, wherein the human-machine interface is adapted such that the detector may generate an information on the position of the at least one beacon device.

Embodiment 28: The human-machine interface according to the preceding embodiment, wherein the beacon device comprises at least one illumination source adapted to generate at least one light beam to be transmitted to the detector.

Embodiment 29: An entertainment device for carrying out at least one entertainment function, wherein the entertainment device comprises at least one human-machine interface according to any one of the preceding embodiments relating to a human-machine interface, 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 30: A tracking system for tracking the position of at least one movable object, the tracking system comprising at least one detector according to any one of the preceding embodiments referring to a detector, 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, each position comprising at least one item of information on at least a longitudinal position of the object at a specific point in time.

Embodiment 31: The tracking system according to the preceding embodiment, wherein the tracking system further comprises at least one beacon device connectable to the object, wherein the tracking system is adapted such that the detector may generate an information on the position of the object of the at least one beacon device

Embodiment 32: A scanning system for determining at least one position of at least one object, the scanning system comprising at least one detector according to any one of the preceding embodiments relating to a detector, the scanning system further comprising at least one illumination source adapted to emit at least one light beam configured for an illumination of at least one dot located at at least one surface of the at least one object, wherein the scanning system is designed to generate at least one item of information about the distance between the at least one dot and the scanning system by using the at least one detector.

Embodiment 33: The scanning system according to the preceding embodiment, wherein the illumination source comprises at least one 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.

Embodiment 34: The scanning system according to any one of the two preceding embodiments, wherein the illumination source emits a plurality of individual light beams, in particular an array of light beams exhibiting a respective pitch, in particular a regular pitch.

Embodiment 35: The scanning system according to any one of the three preceding embodiments relating to a scanning system, wherein the scanning system comprises at least one housing.

Embodiment 36: The scanning system according to the preceding embodiment, wherein the at least one item of information about the distance between the at least one dot and the scanning system distance is determined between the at least one dot and a specific point on the housing of the scanning system, in particular a front edge or a back edge of the housing.

Embodiment 37: The scanning system according to any one of the two preceding embodiments, wherein the housing comprises at least one of a display, a button, a fastening unit, a leveling unit.

Embodiment 38: A stereoscopic system comprising at least one tracking system according to any one of the preceding embodiments relating to a tracking system and at least one scanning system according to any one of the preceding embodiments relating to a scanning system, wherein the tracking system and the scanning system each comprise at least one longitudinal optical sensor which are located in a collimated arrangement in a manner that they are aligned in an orientation parallel to the optical axis of the stereoscopic system and exhibit an individual displacement in the orientation perpendicular to the optical axis of the stereoscopic system.

Embodiment 39: The stereoscopic system according to the preceding embodiment, wherein the tracking system and the scanning system each comprise at least one longitudinal optical sensor, wherein the sensor signals of the longitudinal optical sensors are combined for determining the item of information on the longitudinal position of the object.

Embodiment 40: The stereoscopic system according to the preceding embodiment, wherein the sensor signals of the longitudinal optical sensors are distinguishable with respect to each other by applying a different modulation frequency.

Embodiment 41: The stereoscopic system according to the preceding embodiment, wherein the stereoscopic system further comprises at least one transversal optical sensor, wherein the sensor signals of the transversal optical sensor are used for determining the item of information on the transversal position of the object.

Embodiment 42: The stereoscopic system according to the preceding embodiment, wherein a stereoscopic view of the object is obtained by combining the item of information on the longitudinal position of the object and the item of information on the transversal position of the object.

Embodiment 43: A use of a detector according to any one of the preceding embodiments referring to a detector, for a purpose of use selected from the group consisting of: a distance measurement, in particular in traffic technology; a position measurement, in particular in traffic technology; an entertainment application; a security application; a human-machine interface application; a tracking application; a scanning application; in stereoscopic vision; 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 distance and/or position measurement of objects with a thermal signature; a machine vision application; a robotic application; a logistics application; a vehicle application, an airplane application, a ship application, a spacecraft application, a robotic application, a medical application, a sports' application, a building application, a construction application, a manufacturing application, a machine vision application; a use in combination with at least one sensing technology selected from time-of-flight detector, radar, Lidar, ultrasonic sensors, or interferometry; an infra-red detection application.

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 alone or with features in combination. 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 exemplary embodiment of a detector according to the present invention comprising a longitudinal optical sensor and a bias light source;
Figure 2	shows experimental results demonstrating an effect of using bias light by using the detector according to Figure 1;
Figure 3	shows further experimental results demonstrating an effect of using bias light by using the detector according to Figure 1;
Figure 4	shows an exemplary embodiment of an optical detector, a detector system, a human-machine interface, an entertainment device, a tracking system and a camera according to the present invention.

Exemplary embodiments

Figure 1 illustrates, in a highly schematic fashion, an exemplary embodiment of an optical detector 110 according to the present invention, in particular for determining a position of at least one object 112. The optical detector 110 comprises at least one optical sensor 114, in particular a longitudinal optical sensor, which, in this particular embodiment, is arranged along an optical axis 116 of the detector 110. Specifically, the optical axis 116 may be an axis of symmetry and/or rotation of the setup of the optical sensors 114. The longitudinal optical sensor 114 may be located inside a housing 118 (not shown in Figure 1) of the detector 110. An opening 124 in the housing 118, which may, particularly, be located concentrically with regard to the optical axis 116, preferably defines a direction of view 126 of the detector 110.

Further, at least one transfer device 120 may be comprised, preferably a refractive lens 122. A coordinate system 128 may be defined, in which a direction parallel or antiparallel to the optical axis 116 is defined as a longitudinal direction, whereas directions perpendicular to the optical axis 116 may be defined as transversal directions. In the coordinate system 128, symbolically depicted in Figure 1, a longitudinal direction is denoted by z and transversal directions are denoted by x and y, respectively. However, other types of coordinate systems 128 are feasible.

The longitudinal optical sensor 114 has at least one sensor region 130 for an incident target light beam 132 originating from the object 112. The sensor region 130 may be designed to generate at least one sensor signal, in particular at least one longitudinal sensor signal, in a manner dependent on an illumination of the sensor region 130 by the light beam 132 originating from the object 112. Thus, according to the FiP effect, the longitudinal sensor signal, given the same total power of the illumination, is dependent on a beam cross-section of the light beam 132 in the sensor region 130. The sensor region 130 comprises at least one semiconducting material. The semiconducting material may comprise a material selected from the group consisting of: amorphous silicon (a-Si); an alloy comprising amorphous silicon; hydrogenated amorphous silicon (a-Si:H); microcrystalline silicon (µc-Si); hydrogenated microcrystalline silicon (µc-Si:H); hydrogenated amorphous silicon carbon alloy (a-SiC:H); hydrogenated amorphous germanium silicon alloy (a-GeSi:H); microcrystalline CIGS; microcrystalline CIS; microcrystalline CZTS; microcrystalline CdTe; crystalline silicon (c-Si); crystalline germanium (c-Ge); crystalline Silicon Germanium alloy (c-SiGe); extrinsic silicon; extrinsic germanium; InGaAs; extended InGaAs; InAs; InSb; GaP; GaN; SiC; organic semiconductors; a semiconductive metal oxid, in particular a n-conductive semiconductive metal oxid, for example titanium dioxide (TiO_2), in particular dye sensitized titanium dioxide (TiO_2). For example, with respect to design of the longitudinal optical sensor 114 and sensor region 130 reference may be made to the optical sensor as disclosed in WO 2016/120392 A1.

The detector 110 comprises at least one evaluation device 134. The evaluation device 140 is, generally, designed to generate at least one item of information on a position of the object 112 by evaluating the sensor signal of the longitudinal optical sensor 114. For this purpose, the evaluation device 134 may comprise one or more electronic devices and/or one or more software components, in order to evaluate the sensor signals, which are symbolically denoted by a longitudinal evaluation unit 136 (denoted by “z”). As will be explained below in more detail, the evaluation device 134 may be adapted to determine the at least one item of information on the longitudinal position of the object 112 by comparing more than one longitudinal sensor signals of the longitudinal optical sensor 114.

As explained above, the longitudinal sensor signal as provided by the longitudinal optical sensor 114 upon impingement by the light beam 132 depends on an electrically detectable property of a material in the sensor region. In order to determine a variation of the electrically detectable property of the material in the sensor region it may, as schematically depicted in Figure 1, therefore be advantageous to measure a current, which may also be denominated a “photocurrent”, through the longitudinal optical sensor 114.

The light beam 132 for illumining the sensor region of the longitudinal optical sensor 114 may be generated by a light-emitting object 112. Alternatively or in addition, the light beam 132 may be generated by a separate illumination source 138 (not shown in Figure 1), which may include an ambient light source and/or an artificial light source, such as a light-emitting diode, being adapted to illuminate the object 112 that the object 112 may be able to reflect at least a part of the light generated by the illumination source 138 in a manner that the light beam 132 may be configured to reach the sensor region of the longitudinal optical sensor 114.

In a specific embodiment, the illumination source 138 may be a modulated light source, wherein one or more modulation properties of the illumination source 138 may be controlled by at least one optional modulation device. Alternatively or in addition, the modulation may be effected in a beam path between the illumination source 138 and the object 112 and/or between the object 112 and the longitudinal optical sensor 114. Further possibilities may be conceivable. In this specific embodiment, it may be advantageous taking into account one or more of the modulation properties, in particular the modulation frequency, when evaluating the sensor signal of the transversal optical sensor 114 for determining the at least one item of information on the position of the object 112.

Generally, the evaluation device 134 may be part of a data processing device and/or may comprise one or more data processing devices. The evaluation device 134 may be fully or partially integrated into the housing 118 and/or may fully or partially be embodied as a separate device which is electrically connected in a wireless or wire-bound fashion to the longitudinal optical sensor 114. The evaluation device 134 may further comprise one or more additional components, such as one or more electronic hardware components and/or one or more software components, such as one or more measurement units and/or one or more evaluation units and/or one or more controlling units (not depicted here).

The detector 110 comprises at least one bias light source 140. The bias light source 140 is designed to generate at least one bias light beam 142 for at least partially illuminating the sensor region 130. The bias light source 140 may be designed to generate the at least one bias light beam 142 for illuminating the whole sensor region 130. The bias light source 140 may be arranged such that the bias light beam 142 impinges on the sensor region 130 directly, i.e. without previously illuminating the object 112 and without being reflected by the object 112. The detector 110 and/or the bias light source 140 may comprise optical elements, such as at least one mirror and/or at least one lens, adapted to direct the bias light beam 142 on the sensor region 130.

The bias light beam 142 may be monochromatic or polychromatic. In particular, the bias light beam 142 may be polychromatic within a small wavelength range, for example, within the IR-wavelength range. The wavelength and/or wavelength range of the bias light beam 142 may be adjustable. The bias light source 140 may comprise at least one monochromatic light source, e.g. at least one laser source, in particular a laser diode, and/or at least one a light emitting diode. The bias light source may be at least one incandescent lamp, at least one heater element or other element at elevated temperature. The temperature can be tuned to supply the intended spectral range. Alternatively, the bias light source 140 may comprise at least one polychromatic light source and at least one filter element adapted to adjust the wavelength of the bias light beam 142. The bias light source 140 may be adapted to generate a long wavelength illumination. In particular, the bias light beam 142 may have a long wavelength. The bias light source 140 may comprise at least one infrared light source. The bias light beam 142 may have a wavelength in the infrared spectral range, preferably within the near infrared (NIR) spectral range spectral range, preferably, from 760 nm to 1400 nm. For example, the bias light beam 142 may have a wavelength of 850 nm. For example, the bias light beam 142 may have a wavelength of 930 nm. For example, the bias light beam 142 may have a wavelength of 1050 nm. The bias light beam 142 may have a different or same wavelength as the light beam 132 originating from the object 112.

The bias light source 140 may be adapted to uniformly illuminate the sensor region 130. In particular, the bias light source 140 may be adapted to illuminate uniformly the sensor region 130 during an entire measurement time and/or a measurement interval. The illumination with the bias light beam 142 may be homogenous on the sensor region 130. In particular, the bias light source 140 may be adapted to illuminate the entire sensor region 130 or the illuminated parts of the sensor region 130 with essential equal luminosity and/or brightness and/or intensity.

The bias light source 140 may be adapted to weakly illuminate the sensor region 130. In particular, the wavelength of the bias light beam 142 may be different from a wavelength of an absorption maximum of the material of the sensor region 130 such that the bias light beam 142 may be weakly absorbed by the sensor region 130. The bias light source 140 may be adapted to illuminate the sensor region 130 with the bias light beam 142 having a wavelength deviating from a wavelength at an absorption maxima of the sensor region 130. For example, the longitudinal optical sensor may be adapted to absorb 10% of the bias light beam 142, preferably 1% of the bias light beam 142 and more preferably 0.1% of the bias light beam 142. However, other embodiments are feasible.

The bias light source 140 may be adapted to illuminate the sensor region 130 such that the longitudinal optical sensor 114 has an immediate and/or a short response behavior. As outlined above, optical sensors comprising semiconducting materials, for example amorphous silicon, hydrogenated amorphous silicon, hydrogenated microcrystalline silicon, hydrogenated amorphous silicon carbon alloy or hydrogenated amorphous germanium silicon alloy, show a long term temporal response behavior over several seconds. For example, this behavior can be observed in case the detector is illuminated after a long period of darkness. Without wishing to be bound by theory, this behavior may be caused by charging of deep trap states of the semiconductor, for example of a-Si:H. The trap sited may have charge carrier trapping lifetimes of seconds and may be located deeply within the bandgap. However, for several applications and purposes immediate or short response behavior is needed. The bias light beam 142 may be adapted to illuminate the sensor region 130 such that the deep trap states are occupied, resulting in immediate and/or a short response behavior.

The longitudinal optical sensor 114 may be at least partially transparent for the bias light beam 142. The detector 110 may comprise a stack of longitudinal optical sensors 114 and the bias light source 140 may be adapted to illuminate a stack of several longitudinal optical sensors 114, e.g. a stack of several a-Si:H-cells. Each of the longitudinal optical sensors 114 may be transparent to the bias light beam 142 . In particular, each of the longitudinal optical sensors 114 may be transparent to the bias light beam having a wavelength in the IR region. For example, even very thick a-Si:H layers, which absorb almost the light beam originating from the object, may be transparent for the bias light beam having a wavelength in the IR region.

Furthermore, the longitudinal optical sensor 114 may be at least partially transparent with respect to the light beam 132 originating from the object 112. Thus, generally, the longitudinal optical sensor 114 may comprise at least one at least partially transparent optical sensor such that the light beam 132 originating from the object at least partially may pass through the longitudinal optical sensor 114. In order to provide a sensory effect, generally, the longitudinal optical sensor 114 typically has to provide some sort of interaction between the light beam 132 originating from the object 112 and the longitudinal optical sensor 114 which typically results in a loss of transparency. The transparency of the longitudinal optical sensor 114 may be dependent on a wavelength of the light beam 132, resulting in a spectral profile of a sensitivity, an absorption or a transparency of the longitudinal optical sensor 114. In case a plurality of longitudinal optical sensors 114 is provided, such as a stack of longitudinal optical sensors 114, preferably all longitudinal optical sensors 114 of the plurality and/or the stack are transparent.

The longitudinal optical sensor 114 may be adapted to generate the at least one longitudinal sensor signal without contribution of the at least one bias light beam 142. The bias light beam 142, in particular the bias light beam 142 having a wavelength in the IR region, may be adapted to illuminate the sensor region 130 such that the trap levels are activated. The bias light beam 142, in particular the bias light beam 142 having a wavelength in the IR region, may be adapted to illuminate the sensor region 130 such that no charge carriers are generated which get extracted. Thus, the longitudinal signal may be generated without contributions caused by the illumination of the bias light beam 142, such as additional DC current, and without additional noise.

In Figure 2 experimental results demonstrating an effect of using bias light by using the detector according to Figure 1 are depicted. The experimental setup was as follows: An aSi-cell was used as longitudinal optical sensor 114. The transfer device 120 had a focal length of 50 mm, e.g. commercially available as Nikon 1.2. As object 112 a light emitting diode was used with different wavelength and a frequency of 370 Hz. The bias light beam 142 had a wavelength of 940 nm. For the experiment, the distance of the longitudinal optical sensor 114 to the object 112 was varied. The optical detector 110 according to the present invention may be arranged in a manner that it clearly exhibits the above-described FiP effect, i.e. the observation of a minimum of the longitudinal sensor signal under a condition in which the sensor region 130 is impinged by the light beam 132 with the smallest possible cross-section, which occurs in this setup when the sensor region 130 is located at a focal point as effected by the refractive lens 122. Thus, the distance from the longitudinal optical sensor 114 and the object was varied from a position wherein the longitudinal optical sensor 114 was in focus of the transfer device 120 to a position out of focus. In particular, the longitudinal optical sensor 114 was moved with respect to the transfer device 120, whereas position of object 112 and transfer device 120 was kept unchanged. The longitudinal optical sensor 114 was moved through the focus such that at a starting position and at an end position the longitudinal optical sensor 114 was positioned out of focus, wherein during movement from the starting position to the end position the longitudinal optical sensor 114 was positioned in the focal point. In Figure 2, photocurrent amplitude I is shown as a function of time t. The left side (until t = 7500 to 10000) of Figure 2 shows measurement results without bias light beam 142. During measurement time from t = 0 to 7500 the sensor signal, in particular FiP-curve, was measured while moving the longitudinal optical sensor 114 with respect to the transfer device 120 without bias light. Then, the bias light was switched on, visible as steps in the curves at t=7500-10000. Afterwards, the sensor signal, in particular FiP-curve, was measured while moving the longitudinal optical sensor 114 with respect to the transfer device 120 with bias light. The right side of Figure 2 shows the measurement results with bias light beam 142. In Figure 2, the photocurrent of the longitudinal optical sensor 114 has been measured under three different kinds of experimental conditions. Curve 144 (solid line) shows the current for a wavelength of 405 nm of the light beam 132 originating from the object 112. Curve 146 (dotted line) shows the current for a wavelength of 505 nm of the light beam 132 originating from the object 112. Curve 148 (dashed line) shows the current for a wavelength of 660 nm of the light beam 132 originating from the object 112. With bias light beam 142 the curves are symmetric, in particular visible in circle 150. Without bias light beam 142 the curves are non-symmetric, in particular visible in circle 152. The longitudinal optical sensor 114, when moved out of focus, required time until it gives a constant signal.

In Figure 3 further experimental results demonstrating an effect of using bias light by using the detector 110 according to Figure 1 are depicted. The experimental setup was as follows: An aSi-cell was used as longitudinal optical sensor 114. The transfer device 120 had a focal length of 50 mm, e.g. commercially available as Nikon 1.2. As object 112 a light emitting diode was used with a wavelength of 530 nm and a modulation frequency of 370 Hz. The bias light beam 142 had a wavelength of 850 nm. In Figure 3, photocurrent amplitude I is shown as a function of time t. In the first time interval, marked with line 154, the photocurrent is shown with applying the bias light beam 142. In the subsequent second time interval, marked with line 156, the photocurrent is shown without applying the bias light beam 142. In the subsequent third time interval again the photocurrent is shown with applying the bias light beam 142. In the first and third time interval the curve shows a smooth shape with small dips, e.g. in a region marked with a circle in the first region. In the second time interval, without the bias light, the curve exhibits larger dips, e.g. in a region marked with a circle in the second time interval.

Figure 4 shows an exemplary embodiment of a detector system 158, comprising at least one optical detector 110, such as the optical detector 110 as disclosed in the embodiment shown in

Figure 1. Herein, the optical detector 110 may be employed as a camera 160, specifically for 3D imaging, which may be made for acquiring images and/or image sequences, such as digital video clips. Further, Figure 4 shows an exemplary embodiment of a human-machine interface 162, which comprises the at least one detector 110 and/or the at least one detector system 158, and, further, an exemplary embodiment of an entertainment device 164 comprising the human-machine interface 162. Figure 4 further shows an embodiment of a tracking system 166 adapted for tracking a position of at least one object 112, which comprises the detector 110 and/or the detector system 158.

With regard to the optical detector 110 and to the detector system 158, reference may be made to the full disclosure of this application. Basically, all potential embodiments of the detector 110 may also be embodied in the embodiment shown in Figure 4. The evaluation device 134 may be connected to each of the at least two longitudinal optical sensors 114, in particular, by the signal leads 168. By way of example, the signal leads 168 may be provided and/or one or more interfaces, which may be wireless interfaces and/or wire-bound interfaces. Further, the signal leads 168 may comprise one or more drivers and/or one or more measurement devices for generating sensor signals and/or for modifying sensor signals.

As described above, the optical detector 110 may comprise a single longitudinal optical sensor 114 or, as e.g. disclosed in WO 2014/097181 A1, a stack of longitudinal optical sensors 114, particularly in combination with one or more transversal optical sensors 170. As an example, one or more at least partially transparent transversal optical sensors 170 may be located on a side of the stack of longitudinal optical sensors 114 facing towards the object 112. Alternatively or additionally, one or more transversal optical sensors 170 may be located on a side of the stack of longitudinal optical sensors 114 facing away from the object 112. In this case the last of the transversal optical sensors 170 may be intransparent. Thus, in a case in which determining the x- and/or y-coordinate of the object in addition to the z-coordinate may be desired, it may be advantageous to employ, in addition to the at one longitudinal optical sensor 114 at least one transversal optical sensor 170 which may provide at least one transversal sensor signal. For potential embodiments of the transversal optical sensor, reference may be made to WO 2014/097181 A1. As described therein, a use of two or, preferably, three longitudinal optical sensors 114 may support the evaluation of the longitudinal sensor signals without any remaining ambiguity. However, embodiments which may only comprise a single longitudinal optical 114 sensor but no transversal optical sensor 170 may still be possible, such as in a case wherein only determining the depth, i.e. the z-coordinate, of the object may be desired. The at least one optional transversal optical sensor 170 may further be connected to the evaluation device 134, in particular, by the signal leads 168.

Further, the at least one transfer device 120 may be provided, in particular as the refractive lens 122 or convex mirror. The optical detector 110 may further comprise the at least one housing 118 which, as an example, may encase one or more of components 114, 170.

Further, the evaluation device 134 may fully or partially be integrated into the optical sensors 114, 170 and/or into other components of the optical detector 110. The evaluation device 134 may also be enclosed into housing 118 and/or into a separate housing. The evaluation device 134 may comprise one or more electronic devices and/or one or more software components, in order to evaluate the sensor signals, which are symbolically denoted by the longitudinal evaluation unit 136 (denoted by “z”) and a transversal evaluation unit 172 (denoted by “xy”) and. By combining results derived by these evolution units 136, 172, a position information 174, preferably a three-dimensional position information, may be generated (denoted by “x, y, z”).

Further, the optical detector 110 and/or to the detector system 158 may comprise an imaging device 176 which may be configured in various ways. Thus, as depicted in Figure 4, the imaging device 176 can for example be part of the detector 110 within the detector housing 118. Herein, the imaging device signal may be transmitted by one or more imaging device signal leads 168 to the evaluation device 134 of the detector 110. Alternatively, the imaging device 176 may be separately located outside the detector housing 118. The imaging device 176 may be fully or partially transparent or intransparent. The imaging device 176 may be or may comprise an organic imaging device or an inorganic imaging device. Preferably, the imaging device 176 may comprise at least one matrix of pixels, wherein the matrix of pixels may particularly be selected from the group consisting of: an inorganic semiconductor sensor device such as a CCD chip and/or a CMOS chip; an organic semiconductor sensor device.

In the exemplary embodiment as shown in Figure 4, the object 112 to be detected, as an example, may be designed as an article of sports equipment and/or may form a control element 178, the position and/or orientation of which may be manipulated by a user 180. Thus, generally, in the embodiment shown in Figure 4 or in any other embodiment of the detector system 158, the human-machine interface 162, the entertainment device 164 or the tracking system 166, the object 112 itself may be part of the named devices and, specifically, may comprise the at least one control element 178, specifically, wherein the at least one control element 178 has one or more beacon devices 182, wherein a position and/or orientation of the control element 178 preferably may be manipulated by user 180. As an example, the object 112 may be or may comprise one or more of 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 180 may be considered as the object 112, the position of which shall be detected. As an example, the user 180 may carry one or more of the beacon devices 182 attached directly or indirectly to his or her body.

The optical detector 110 may be adapted to determine at least one item on a longitudinal position of one or more of the beacon devices 182 and, optionally, at least one item of information regarding a transversal position thereof, and/or at least one other item of information regarding the longitudinal position of the object 112 and, optionally, at least one item of information regarding a transversal position of the object 112. Particularly, the optical detector 110 may be adapted for identifying colors and/or for imaging the object 112, such as different colors of the object 112, more particularly, the color of the beacon devices 182 which might comprise different colors.

The longitudinal optical sensor 114 may be arranged along an optical axis 116 of the detector 110. Specifically, the optical axis 116 may be an axis of symmetry and/or rotation of the setup of the optical sensors 114. The optical sensors 114 may be located inside the housing 118 of the detector 110. An opening 184 in the housing 118, which may, particularly, be located concentrically with regard to the optical axis 116, preferably defines a direction of view 186 of the detector 110. The coordinate system 128 may be defined, in which a direction parallel or antiparallel to the optical axis 116 is defined as a longitudinal direction, whereas directions perpendicular to the optical axis 116 may be defined as transversal directions.

The optical detector 110 may be adapted for determining the position of the at least one object 112. Additionally, the optical detector 110, specifically an embodiment including the camera 160, may be adapted for acquiring at least one image of the object 112, preferably a 3D-image. As outlined above, the determination of a position of the object 112 and/or a part thereof by using the optical detector 110 and/or the detector system 158 may be used for providing a human-machine interface 162, in order to provide at least one item of information to a machine 188. In the embodiments schematically depicted in Figure 4, the machine 188 may be or may comprise at least one computer and/or a computer system comprising a data processing device 190. Other embodiments are feasible. The evaluation device 134 may be a computer and/or may comprise a computer and/or may fully or partially be embodied as a separate device and/or may fully or partially be integrated into the machine 188, particularly the computer. The same holds true for a track controller 192 of the tracking system 166, which may fully or partially form a part of the evaluation device 134 and/or the machine 188.

Similarly, as outlined above, the human-machine interface 162 may form part of the entertainment device 164. Thus, by means of the user 180 functioning as the object 112 and/or by means of the user 180 handling the object 112 and/or the control element 178 functioning as the object 112, the user 180 may input at least one item of information, such as at least one control command, into the machine 188, particularly the computer, thereby varying the entertainment function, such as controlling the course of a computer game.

List of reference numbers

110	detector
112	object
114	optical sensor
116	optical axis
118	housing
120	transfer device
122	refractive lens
124	opening
126	direction of view
128	coordinate system
130	sensor region
132	target light beam
134	evaluation device
136	longitudinal evaluation unit
138	illumination source
140	bias light source
142	bias light beam
144	curve
146	curve
148	curve
150	circle
152	circle
154	line
156	line
158	detector system
160	camera
162	human-machine interface
164	entertainment device
166	tracking system
168	signal leads
170	transversal optical sensors
172	transversal evaluation unit
174	position information
176	imaging device
178	control element
180	user
182	beacon devices
184	opening
186	direction of view
188	machine
190	data processing device
192	track controller

Patent claims

1. A detector (110) for an optical detection, comprising:
    - at least one optical sensor (114), the optical sensor (114) has at least one sensor region (130) for an incident target light beam (132), wherein the sensor region (130) is designed to generate at least one sensor signal in a manner dependent on an illumination of the sensor region (130) by the target light beam (132), wherein the sensor region (130) comprises at least one semiconducting material;
    - at least one evaluation device (134), wherein the evaluation device (134) is designed to generate at least one item of information on the target light beam (132) by evaluating the sensor signal; and
    - at least one bias light source (140), wherein the bias light source (140) is designed to generate at least one bias light beam (142) for at least partially illuminating the sensor region (130).

2. The detector (110) according to the preceding claim, wherein the bias light source (140) is adapted to one or both of uniformly or weakly illuminate the sensor region (130).

3. The detector (110) according to any one of the preceding claims, wherein the bias light source (140) is adapted to generate a long wavelength illumination.

4. The detector (110) according to any one of the preceding claims, wherein the bias light source (140) comprises at least one infrared light source, wherein the bias light beam (142) has a wavelength in the infrared spectral range.

5. The detector (110) according to any one of the preceding claims, wherein the bias light source (140) is designed to generate the at least one bias light beam (142) for illuminating the whole sensor region (130).

6. The detector (110) according to any one of the preceding claims, wherein the bias light source (140) is adapted to illuminate the sensor region (130) such that the optical sensor (114) has an immediate and/or a short response behavior.

7. The detector (110) according to any one of the preceding claims, wherein the optical sensor (114) is adapted to generate the at least one sensor signal without contribution of the at least one bias light beam (142).

8. The detector (110) according to any one of the preceding claims, wherein the semiconductor material comprises a material selected from the group consisting of: amorphous silicon (a-Si); an alloy comprising amorphous silicon; hydrogenated amorphous silicon (a-Si:H); microcrystalline silicon (µc-Si); hydrogenated microcrystalline silicon (µc-Si:H); hydrogenated amorphous silicon carbon alloy (a-SiC:H); hydrogenated amorphous germanium silicon alloy (a-GeSi:H); microcrystalline CIGS; microcrystalline CIS; microcrystalline CZTS; microcrystalline CdTe; crystalline silicon (c-Si); crystalline

germanium (c-Ge); crystalline Silicon Germanium alloy (c-SiGe); extrinsic silicon; extrinsic germanium; InGaAs; extended InGaAs; InAs; InSb; GaP; GaN; SiC; organic semiconductors; a semiconductive metal oxid, in particular a n-conductive semiconductive metal oxid, for example titanium dioxide (TiO_2), in particular dye sensitized titanium dioxide (TiO_2).

9. The detector (110) according to any one of the preceding claims, wherein the optical sensor (114) is at least partially transparent for the bias light beam (142).

10. The detector according to any one of the preceding claims, wherein the optical sensor is a longitudinal optical sensor, wherein the sensor region is designed to generate at least one longitudinal sensor signal in a manner dependent on an illumination of the sensor region by the target light beam, wherein the longitudinal sensor signal, given the same total power of the illumination, is dependent on a beam cross-section of the target light beam in the sensor region, wherein the evaluation device is designed to generate at least one item of information on a longitudinal position of at least one object by evaluating the longitudinal sensor signal.

11. A detector system (158) for determining a position of at least one object (112), the detector system (158) comprising at least one detector (110) according to any one of the preceding claims, the detector system (158) further comprising at least one beacon device (182) adapted to direct at least one light beam (132) towards the detector (110), wherein the beacon device (182) is at least one of attachable to the object (112), holdable by the object (112) and integratable into the object (112).

12. A method for an optical detection, in particular using a detector (110) according to any of the preceding claims relating to a detector, comprising the following steps:
    - generating at least one sensor signal by using at least one optical sensor (114), wherein the sensor signal is dependent on an illumination of a sensor region (139) of the optical sensor (114) by a target light beam (132), wherein the sensor region (130) comprises at least one semiconducting material;
    - evaluating the sensor signal by using at least one evaluation device (134) and generating at least one item of information on the target light beam (132); and
    - generating at least one bias light beam (142) by using at least one bias light source (140) and at least partially illuminating the sensor region (130).

13. A human-machine interface (162) for exchanging at least one item of information between a user (180) and a machine (188), wherein the human-machine interface (162) comprises at least one detector (110) according to any one of the preceding claims relating to a detector, wherein the human-machine interface (162) is designed to generate at least one item of geometrical information of the user by means of the detector (110) wherein the

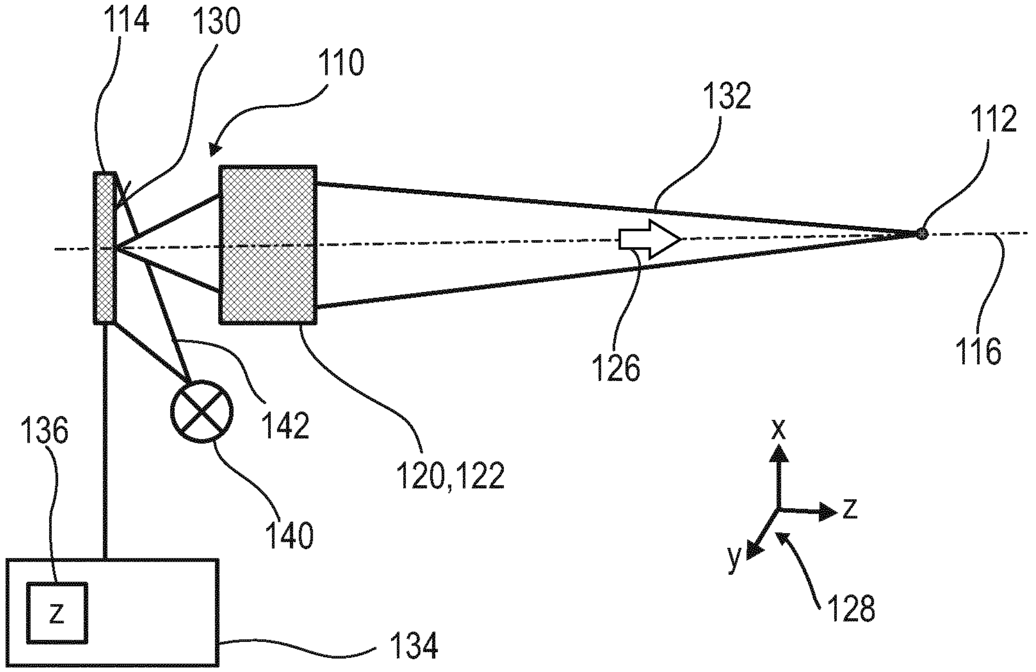
human-machine interface (162) is designed to assign to the geometrical information at least one item of information.

14. A tracking system (166) for tracking the position of at least one movable object (112), the tracking system (166) comprising at least one detector (110) according to any one of the preceding claims referring to a detector, the tracking system (166) further comprising at least one track controller (192), wherein the track controller (192) is adapted to track a series of positions of the object (112), each position comprising at least one item of information on at least a longitudinal position of the object (112) at a specific point in time.

15. A scanning system for determining at least one position of at least one object (112), the scanning system comprising at least one detector (110) according to any one of the preceding claims relating to a detector, the scanning system further comprising at least one illumination source (138) adapted to emit at least one light beam configured for an illumination of at least one dot located at at least one surface of the at least one object (112), wherein the scanning system is designed to generate at least one item of information about the distance between the at least one dot and the scanning system by using the at least one detector (110).

16. A use of a detector (110) according to any one of the preceding claims referring to a detector, for a purpose of use selected from the group consisting of: a distance measurement, in particular in traffic technology; a position measurement, in particular in traffic technology; an entertainment application; a security application; a human-machine interface application; a tracking application; a scanning application; in stereoscopic vision; 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 distance and/or position measurement of objects with a thermal signature; a machine vision application; a robotic application; a logistics application; a vehicle application, an airplane application, a ship application, a spacecraft application, a robotic application, a medical application, a sports’ application, a building application, a construction application, a manufacturing application, a machine vision application; a use in combination with at least one sensing technology selected from time-of-flight detector, radar, Lidar, ultrasonic sensors, or interferometry; an infra-red detection application.

FIG.1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126
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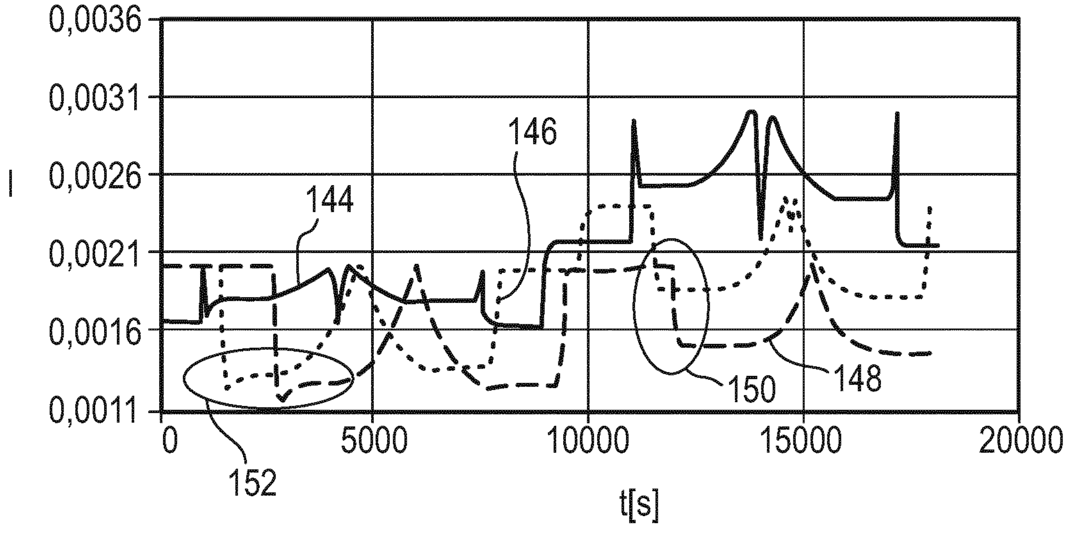
136
140
120,122
x
z
y
128
z
134

FIG.2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150
152

FIG.3

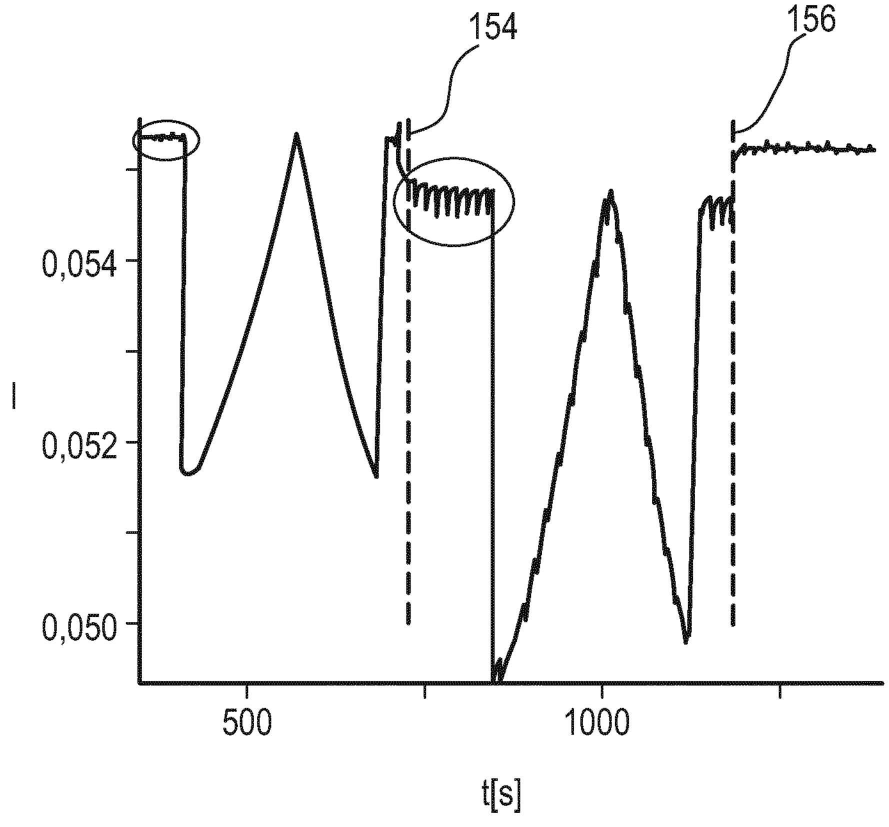
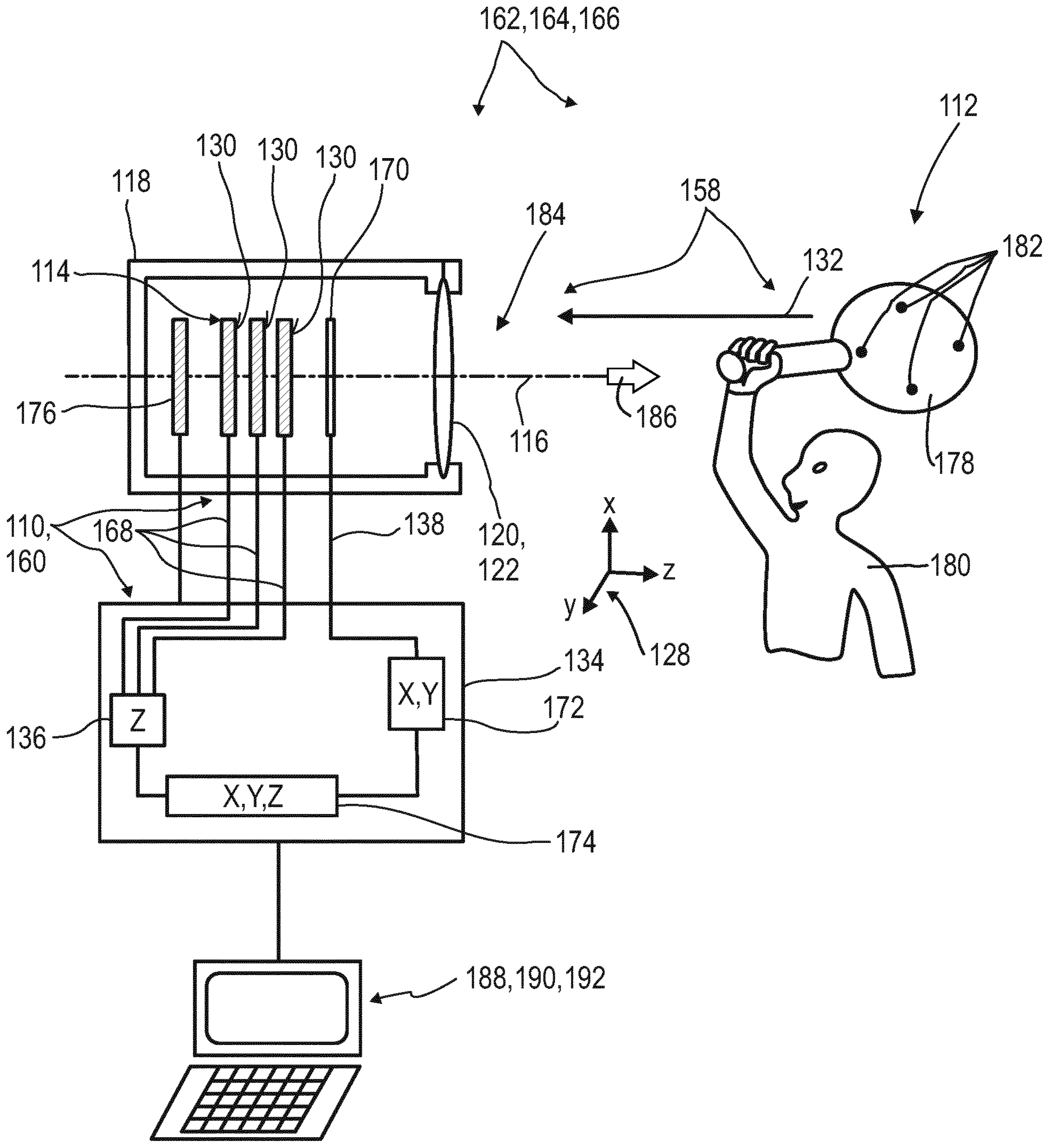


FIG.4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138
120,
122
x
z
y
128
180
134
136
Z
X,Y
172
X,Y,Z
174
188,190,192

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2017/083730

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01S17/32 G01S17/42 G01S17/46 G01S17/89 G01S3/783
G01S7/481 G01S7/497 G06F3/03 G01S5/16

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 G06F

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 2016/364015 A1 (SEND ROBERT [DE] ET AL) 15 December 2016 (2016-12-15) paragraphs [0345], [0347], [0207], [0351], [0350], [0156], [0363], [0156], [0036], [0070], [0256], [0076], [0077]; figures 2-7 paragraphs [0097] - [0101], [0065], [0056] - [0057], [0336], [0347], [0081], [0208], [0369], [0181], [0001], [0224], [0330] paragraphs [0332], [0216], [0017], [0219] -----	1-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 March 2018	16/03/2018

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/083730

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016364015 A1	15-12-2016	CN 105637382 A	01-06-2016
		EP 3036558 A1	29-06-2016
		JP 2016536594 A	24-11-2016
		KR 20160044009 A	22-04-2016
		US 2016364015 A1	15-12-2016
		US 2017219694 A1	03-08-2017
		WO 2015024870 A1	26-02-2015