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(54) Title: PROJECTION SYSTEM

(57) **Abstract**: The present invention relates to a metrology system (100) for dimensional measurement of an object (200) comprising a light-projection device (110), LPD, configured to project an image (112) onto the object (200); a position-measurement device (120), PMD, having a measurement volume, configured to determine the position and/or the orientation of the LPD (110) disposed within the measurement volume; a dimensional acquisition device (140), DAD, that is an optical non-contact probe rigidly attached to the LPD configured to acquire dimensional data of the object (200);and an adjustment unit (130) configured to adjust the projected image (112) to have an essentially static appearance in relation to the object (200), which adjustment is responsive to movement of the LPD (110) detected by the PMD (120); wherein the image projected by the LPD (110) conveys feedback information to the user responsive to dimensional acquisition by the DAD (140).

PROJECTION SYSTEM

FIELD OF THE INVENTION

The invention relates to a projection system comprising a light-projection device, configured to adjust the projected image responsive to movement of the light-projection device.

BACKGROUND OF THE INVENTION

Special projecting methods are able to display an image with reference marks directly onto an object, allowing accurate positioning of a tool with respect to a predefined reference point. Such methods may be used for accurately processing sheet material (such as sheet metal, sheet composites, and sheet foil). Usually, the sheet material is positioned in a fixed setup with respect to a fixed projector. An image is projected onto the sheet material, wherein the image serves as a positional reference for a manual, operator guided process (such as sheet cutting, drilling and riveting, or application of decals).

The projector techniques known in the art mostly use a fixed position of the projector, where the position of the sheet can be manually adjusted until reference marks of the image coincide with reference marks of the sheet. For example, the edges of a sheet with known dimensions may be used as such a reference mark. Once properly aligned, the other position references in the image can be used to manually position a tool (such as a marker pen, cutter, or drill) and perform the required action. This method is considered a promising alternative to the traditionally used hard templates.

SUMMARY OF SOME EMBODIMENTS OF THE INVENTION

The present invention provides a metrology system (100) for dimensional measurement of an object (200) comprising:

- a light-projection device (110), LPD, configured to project an image (112) onto the object (200);
- a position-measurement device (120), PMD, having a measurement volume, configured to determine the position and/or the orientation of the LPD (110) disposed within the measurement volume;
- a dimensional acquisition device (140), DAD, that is an optical non-contact probe rigidly attached to the LPD configured to acquire dimensional data of the object (200);

and

- an adjustment unit (130) configured to adjust the projected image (112) to have an essentially static appearance in relation to the object (200), which adjustment is responsive to movement of the LPD (110) detected by the position-measurement device (120), PMD,

wherein the image projected by the LPD (110) conveys feedback information to the user responsive to dimensional acquisition by the DAD (140).

The the adjustment unit (130) may further comprises a processing device (131), configured to receive signals from the PMD (120), process them and output signals to the LPD (111), wherein the processing device (131) is configured to adjust the position and/or orientation of the projected image (112) to have an essentially static appearance in relation to the object (200). The DAD (140) may be a laser scanner. The processing device (131) may be further configured to:

- receive a reference model of the object (200);
- receive data from the PMD (120) as to the position and/or orientation of the LPD (110) relative to the object (200); and
- adjust the projected image responsive to the data received from the PMD (120) using the reference model to calculate the adjustment.

The processing device (131) may be further configured to:

- receive a reference model of the object (200);
- receive data from the DAD (140) as to the acquired dimensions of the object (200); and
- adjust the content of the projected image such that the feedback information indicates geometrical deviations between the acquired dimensions of the object (200) and the reference model.

The geometrical deviations may relate to a dimensional verification of geometrical features of the object (200).

The processing device (131) is further configured such that the feedback information includes suggestions of remedial steps to correct the geometrical deviations in the object.

The processing device (131) may be further configured to:

- receive data from the DAD (140) as to the acquired dimensions of the object (200); and

- adjust the content of the projected image such that the feedback information indicates a local quality of the acquired dimensions of the object (200).

The content of the project image is continuously updated during dimensional acquisition. The LPD (110) may project the image (112) along a projection beam (114), wherein the LPD (110) is configured to allow spatial adjustment of the direction of the projection beam (114). The PMD (120) may be configured to determine the 6 degrees of freedom, 6DOF, related to the position and the orientation of the LPD (110) in relation to the object (200). The present invention also provides a use of a metrology system (100) as described above for dimensional verification of an object (200). The present invention also provides a method for dimensional acquisition of an object, comprising the steps of:

- providing a light-projection device (110), LPD, configured to project an image (112) onto the object (200);
- providing a position-measurement device (120), PMD, having a measurement volume, configured to determine the position and/or the orientation of the LPD (110) disposed within the measurement volume;
- providing a dimensional acquisition device (140), DAD, that is an optical non-contact probe rigidly attached to the LPD configured to acquire dimensional data of the object (200);
- moving the DAD (110) relative to the object (200) to acquire dimensions of the object (200);
- adjusting the projected image (112) to have an essentially static appearance in relation to the object (200), which adjustment is responsive to movement of the LPD (110) detected by the position-measurement device (120), PMD,
- conveying feedback information to the user responsive to dimensional acquisition by the DAD (140), via the image projected by the LPD (110).

The steps may be iterated in real-time.

The present invention also provides a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, configured for adjusting a projected image (112) on an object, responsive to movement of the LPD (110) of a metrology system (100) as described above, or for performing a method as described above.

According to another aspect of the invention, there is provided a projection system comprising:

- a light-projection device, LPD, configured to project an image onto an object;
- a position-measurement device, PMD, configured to determine the position and/or the orientation of the LPD in relation to the object; and
- an adjustment unit configured to adjust the projected image responsive to movement of the LPD detected by the position-measurement device, PMD.

In one embodiment of the invention, the adjustment unit further comprises:

- a processing device, configured to receive signals from the PMD, process them and output signals to the LPD, preferably wherein the processing device is configured to control the position and/or orientation of the projected image on the object.

In another embodiment of the invention, the projected image is adjusted to have an essentially static appearance in relation to the object, responsive to movement of the LPD detected by the PMD.

In another embodiment of the invention, the projection system comprises a dimensional acquisition device, DAD, configured to acquire dimensional data of the object.

In another embodiment of the invention, the DAD is mechanically attached to the LPD.

In another embodiment of the invention, the processing device is further configured to:

- receive dimensional data of the object from a dimensional acquisition device, DAD, configured to acquire dimensional data of the object; and
- adjust the projected image responsive to the dimensional data of the object.

In another embodiment, the processing device is configured to:

- receive a reference model, preferably a computer aided design, CAD, model, of the object;
- receive data from the PMD as to the position and/or orientation of the LPD relative to the object; and

- adjust the projected image responsive to the data received from the PMD using the reference model to calculate the adjustment.

In another embodiment of the invention, the LPD is portable, preferably the LPD is handheld.

In another embodiment of the invention, the LPD projects the image along a projection beam, wherein the LPD is configured to allow spatial adjustment of the direction of the projection beam.

In another embodiment of the invention, the PMD is configured to determine the 6 degrees of freedom, 6DOF, related to the position and the orientation of the LPD or the PMD in relation to the object.

According to a second aspect, the invention encompasses a method for projecting an image onto an object with a projection system, preferably with a projection system according to the first aspect of the invention, comprising the steps of:

- determining the position and/or orientation of an LPD relative to the object; and
- adjusting the projected image responsive to the position and/or orientation of the LPD relative to the object.

In one embodiment of the invention, the position and/or orientation of the LPD relative to the object is detected by a position-measurement device, PMD.

In another embodiment of the invention, the method according to the second aspect of the invention comprises the steps of:

- receiving dimensional data of the object from a dimensional acquisition device, DAD; and
- adjusting the projected image responsive to the dimensional data.

In another embodiment of the invention, the steps are iterated in real-time.

According to a third aspect, the invention encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, configured for adjusting a projected image on an object, responsive to movement of the LPD of a projection system according to the first aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 depicts an illustration of a projection system **100** according to an embodiment of the invention.

FIGs. 2A and **2B** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (solid lines) and after (dashed lines) movement of the light projection device **110** with respect to the object **200**. In **FIG. 2A**, the static image **112** is maintained by adjusting the position of the image **112** within the beam area **115**. In **FIG. 2B**, the static image **112** is maintained by adjusting the direction of the projected beam **114**, and optionally by adjusting the shape of the image **112** to take into account the adjusted angle of direction of the projected beam **114** with respect to the object **200**.

FIGs. 2C and **2D** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2C**) and after (**FIG. 2D**) translational movement of the light projection device **110** with respect to the object **200**. In **FIGs. 2C** and **2D** the static image **112** is maintained by adjusting the position of the image **112** within the beam area **115**. The upper figures are three-dimensional schematic representations of the object and light projection device; the lower figures are side-profiles of the object and light projection device.

FIGs. 2E and **2F** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2E**) and after (**FIG. 2F**) rotational movement of the light projection device **110** with respect to the object **200**. In **FIGs. 2E** and **2F** the static image **112** is maintained by adjusting the position of the image **112** within the beam area **115,** and optionally by adjusting the shape of the image **112** to take into account the adjusted angle of direction of the projected beam **114** with respect to the object **200**. The upper figures are three-dimensional schematic representations of the object and light projection device; the lower figures are side-profiles of the object and light projection device.

FIGs. 2G and **2H** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2G**) and after (**FIG. 2H**) translational movement of the light projection device **110** with respect to the object **200**. In **FIGs. 2G** and **2H** the static image **112** is maintained by adjusting the direction of the projected beam **114**, and optionally by adjusting the shape of the image **112** to take into account the adjusted angle of direction of the projected beam **114** with respect to the object **200**. The upper figures are three-dimensional schematic representations of the object and light projection device; the lower figures are side-profiles of the object and light projection device.

FIGs. 2I and **2J** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2I**) and after (**FIG. 2J**) rotational movement of the light projection device **110** with respect to the object **200**. In **FIGs. 2I** and **2J** the static image **112** is maintained by adjusting the direction of the projected beam **114**. The upper figures are three-dimensional schematic representations of the object and light projection device; the lower figures are side-profiles of the object and light projection device.

FIG. 3 and **FIG. 4** depict a flow chart **500** illustrating the working principle of a processing device **131** of a projection system **100** according to embodiments of the invention.

FIG. 5 depicts a schematic overview of electronic connections according to an embodiment of the invention.

FIG.6 depicts an alternative schematic overview of electronic connections according to an embodiment of the invention.

FIG. 7 depicts a schematic overview of the definitions of azimuth and elevation.

FIGs. 8A and 8B is a schematic illustration of a light projection device **110** containing a steerable mirror for adjusting the position of the projection beam. In FIG. 8B, the projection beam is steered downwards compared with FIG. 8A.

DETAILED DESCRIPTION OF THE INVENTION

While the fixed projection systems in the art are much less expensive than hard templates, they are often limited to simple process information only. They may also require the use of an additional computer screen, which the operator needs to check regularly, distracting him from the task at hand. Furthermore, they may require high levels of training for the operator. Operation time may be slow, since the sheets need to be properly aligned before the task, and sometimes even re-aligned during the task. Due to the extensive set-up, the overall cost can still be relatively high. Moreover, such fixed projection systems are not suitable for objects with more complex geometries. More in particular, low visibility and shadow formation can be an issue.

The present invention aims to provide a projection system which solves one or more of the aforementioned disadvantages. Preferred embodiments of the present invention aim to provide a projection system which solves one or more of the aforementioned disadvantages. The present invention also aims to provide a method which solves one or more of the aforementioned disadvantages. Preferred embodiments of the present invention aim to provide a method which solves one or more of the aforementioned disadvantages.

To solve one or more of the above-described problems, at least one embodiment of the present invention adopts the following constructions as illustrated in the embodiments described below, which are illustrated by the drawings. However, parenthesized or emboldened reference numerals affixed to respective elements merely exemplify the elements by way of example, with which it is not intended to limit the respective elements.

Before the present system and method of the invention are described, it is to be understood that this invention is not limited to particular systems and methods or combinations described, since such systems and methods and combinations may, of course, vary. It is also to be understood that the terminology used herein is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

As used herein, the singular forms "a", "an", and "the" include both singular and plural referents unless the context clearly dictates otherwise.

The terms "comprising", "comprises" and "comprised of" as used herein are synonymous with "including", "includes" or "containing", "contains", and are inclusive or open-ended and do not exclude additional, non-recited members, elements or method steps. It will be appreciated that the terms "comprising", "comprises" and "comprised of" as used herein comprise the terms "consisting of", "consists" and "consists of".

The recitation of numerical ranges by endpoints includes all numbers and fractions subsumed within the respective ranges, as well as the recited endpoints.

Whereas the terms “one or more” or “at least one”, such as one or more or at least one member(s) of a group of members, is clear *per se*, by means of further exemplification, the term encompasses *inter alia* a reference to any one of said members, or to any two or more of said members, such as, *e.g.,* any ≥3, ≥4, ≥5, ≥6 or ≥7 etc. of said members, and up to all said members.

As used herein, the term “change in position” may also comprise a change in orientation. A change in position may be any translational change in (x,y,z) coordinates. A change in orientation may be any rotational change around any axis.

Unless otherwise defined, all terms used in disclosing the invention, including technical and scientific terms, have the meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. By means of further guidance, term definitions are included to better appreciate the teaching of the present invention.

In the following passages, different aspects of the invention are defined in more detail. Each aspect so defined may be combined with any other aspect or aspects unless clearly indicated to the contrary. In particular, any feature indicated as being preferred or advantageous may be combined with any other feature or features indicated as being preferred or advantageous.

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to a person skilled in the art from this disclosure, in one or more embodiments. Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the appended claims, any of the claimed embodiments can be used in any combination.

In the following detailed description of the invention, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration only of specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilised and structural or logical changes may be made without departing from the scope of the present invention. The following detailed description, therefore, is not to be taken in a limiting sense.

According to a first aspect of the present invention, there is provided a projection system **100** comprising:

- a light-projection device **110**, LPD, configured to project an image **112** onto an object **200**;
- a position-measurement device **120**, PMD, configured to determine the position and/or the orientation of the LPD **110** relative to the object **200**, and
- an adjustment unit **130** configured to adjust the projected image **112** responsive to movement of the LPD **110** detected by the position-measurement device **120**, PMD. In an embodiment, the adjustment unit **130** is comprised within the LPD **110**.

A system according to this embodiment will be described with reference to **FIG.1**, which depicts an illustration of projection system **100** of an embodiment of the invention, together with an object **200** upon which an image **112** is projected, and together with an operator **300** who can manually manipulate the position and orientation of the LPD **110**.

In a preferred embodiment, the projected image is adjusted to have an essentially static appearance in relation to the object, responsive to movement of the LPD relative to the object detected by the PMD. By essentially static, it is meant that the projected image position and optionally orientation essentially does not change relative to the object even when the LPD is moved relative to the object. For instance, should an operator move the LPD in a sweeping movement from left to right across the object, the projected image **112** will translate synchronously with the sweeping movement, but from right to left thereby giving the appearance that the projected image **112** is a static projection on the object. Preferably, the object **200** remains stationary while the LPD **110** moves. Systems according to this preferred embodiment will also be described with reference to **FIGs. 2A** to **2J**.

Preferred embodiments of the present invention relate to a projection system **100** as shown, for instance, in **FIGs. 2A** and **2B** comprising a light-projection device **110**, LPD, configured to project an image **112** onto an object **200**. Movements of the LPD **110** are measured using a position-measurement device **120**, PMD, configured to determine the position and/or the orientation of the LPD **110** relative to the object **200**. In **FIGs. 2A** and **2B**, a starting position for the LPD **110**, projection beam **114**, and beam area **115** are shown using solid lines, while displaced positions for LPD **110'**, projection beam **114'**, and beam area **115'** (**FIG. 2A** only) are indicated using dashed lines.

FIGs 2C, **2D**, **2G** and **2F** illustrate the adjustments which may be made after translational movement of the LPD **110** with respect to the object **200**. **FIGs. 2C** and **2D** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2C**) and after (**FIG. 2D**) translational movement of the light projection device **110** with respect to the object **200**, and correspond to the translational movement of the LPD **110** and subsequent adjustments as shown in **FIG. 2A**. In **FIGs. 2C** and **2D** the static image **112** is maintained by adjusting the position of the image **112** within the beam area **115**.

FIGs. 2G and **2H** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2G**) and after (**FIG. 2H**) translational movement of the light projection device **110** with respect to the object **200**, and correspond to the translational movement of the LPD **110** and subsequent adjustments as shown in **FIG. 2B**. In **FIGs. 2G** and **2H** the static image **112** is maintained by adjusting the direction of the projected beam **114**, and optionally by adjusting the shape of the image **112** to take into account the adjusted angle of direction of the projected beam **114** with respect to the object **200**. Adjusting the shape of the image **112** may be performed by modifying the image made by an imager (712 in **Fig. 5**) in the LPD **110**.

FIGs. **2E**, **2F**, **2I** and **2J** illustrate the adjustments which may be made after rotational movement of the LPD **110** with respect to the object **200**. **FIGs. 2E** and **2F** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2E**) and after (**FIG. 2F**) rotational movement of the light projection device **110** with respect to the object **200**. In **FIGs. 2E** and **2F** the static image **112** is maintained by adjusting the position of the image **112** within the beam area **115**, and optionally by adjusting the shape of the image **112** to take into account the adjusted angle of direction of the projected beam **114** with respect to the object **200**. **FIGs. 2I** and **2J** depict an illustration of a light projection device **110** projecting a stable image **112** onto an object **200** before (**FIG. 2I**) and after (**FIG. 2J**) rotational movement of the light projection device **110** with respect to the object **200**. In **FIGs. 2I** and **2J** the static image **112** is maintained by adjusting the direction of the projected beam **114**.

An adjustment unit **130** is preferably configured to maintain the position and/or orientation of the image **112** in fixed relation to the object **200** after movement of the LPD **110** by adjusting the projected image **112** responsive to movement of the LPD **110** relative to the object **200** detected by the position-measurement device **120**. The adjustment may be to the position of the image **112** within the window of the beam area **115'** typically by applying a mathematical transformation to the image; it is appreciated that the direction of projection beam **114**, **114'** can remain static with respect to the LPD **110** as shown in **FIG. 2A**. Alternatively, or in addition, the adjustment may be to the angular direction of the projected image **112** relative to the LPD **110** as shown in **FIG. 2B**; in such case, the projection beam **114'** and projected image **112** therein may be steered using, for instance, a steerable mirror or an adjustable mounting for a projector element within the LPD **110**.

As used herein, the term “light-projection device” or LPD **110** comprises any device that is configured to emit a projection beam **114**, thereby projecting an image **112** onto the surface of an object **200**. The LPD typically comprises a light source together with an imager **712** such as a liquid crystal display (LCD) or digital micromirror device (DMD). The LPD **110** may be a liquid crystal display projector or a digital light processing (DLP) projector. In some embodiments, the projection system **100** comprises a plurality of LPDs **110**. The LPD **110** may incorporate an adjustment unit **130**, for example a mechanical adjustment unit **130** such as a controllably steerable mirror that can change the direction of projection of the projection beam **144** or image **112** from the LPD **110**. The LPD **110** may also incorporate an electronic adjustment unit **130,** such as a computer system, for example a personal computer, comprising a processing device **131**, configured to change the image **112** from the LPD **110**. In an embodiment, the adjustment unit **130** comprises both a mechanical adjustment unit and an electronic adjustment unit. The LPD **110** may be referred to as a ‘mobile light projection system’ (MLPS).

Preferably, the projected image **112** is an image of light. The projected image can be projected on an object **200**, preferably on a target surface **202** of the object **200** as shown in **FIG. 2**. The projection may comprise a projection beam **114** that is essentially a cone of light. The projected image **112** is formed when the projection beam **114** is projected onto the object surface **202**. The area **115** projected by the projection beam **114** on the object surface **202** is known as the beam area **115**.

The image **112** may have an area that is smaller than the beam area **115** as shown in **FIG. 2**; this allows space within the bounds of the beam area **115** for movement of the image **112** over the object surface **202** while keeping the position of the projection beam **114** fixed as shown, for instance, in **FIG. 2A**. While the projection beam **114** may be fixed according to one aspect, it may alternatively or additionally be steerable as depicted in **FIG. 2B**. The projection beam **114** may be fixed or steerable in fixed relation to an internal chassis of the LPD **110**.

In some embodiments, the projected image **112** may contain process information for user feedback for different kinds of industrial processes, thus replacing the need for a computer screen. By projecting the relevant user feedback information onto the area of the object **200** where it applies, the interpretation of the user feedback information may be greatly simplified. In a preferred embodiment, the projected image **112** comprises a laser template on a target surface of the object **200**. The process information may be of several different types. In some embodiments, the projected image **112** comprises one or more items selected from the group comprising: maps, text, icons, work instructions, pointers, and reticles.

The projected image **112** may comprise one or more maps, preferably color coded maps. As used herein, the term “color coded map” refers to a color scheme that is projected onto a surface to indicate that the area that is illuminated to a specific color, is characterized by the value that matches the specific color. Color coded maps can be used to display the local accuracy of the surface geometry. A color coded map contains detailed information that may lead to a local rework of the object in order to get it within specifications of any sort (e.g. to get it within geometric tolerances by applying a grinding process locally on areas with excess of material). Color coded maps can also be used to display any other characteristic of an object, like internal stresses as a result of an FEA (finite element calculation). This could be used to improve the ease of interpretation of the user feedback towards the required improvement action.

Alternatively or in combination with the above, the projected image **112** may comprise text comprising user feedback for interpretation of a process step, for example display of local geometrical deviations, expressed in the appropriate measurement unit (such as mm, microns, inches). The text may also comprise warning messages or error messages. The text may also comprise instructions or work instructions for the operator **300** to carry out as part of a standard process or as a result of the real time process of the ongoing process step, for example to continue removing material at a specific indicated spot on the object **200**.

Alternatively or in combination with the above, the projected image **112** may comprise icon-based information comprising user feedback or operator instructions, which may be projected in the shape of predefined images (e.g. an arrow, an exclamation mark, etc...). The fact that an icon is projected and the location where it is projected on the object **200** may provide information to the operator **300**. For example, an exclamation mark may indicate a problem with a real-time calculation, an arrow may indicate how to move a mobile device in order to find a next feature to investigate, and so on.

Alternatively or in combination with the above, the projected image **112** may comprise reticles (also referred to as reticules or cross hairs) for manual positioning of a tool. A projected cross hair may indicate the location of a manual operation to be carried out, such as the position to drill a hole or where to apply a rivet. Cross hairs can also be used for point-and-shoot indication of a specific location. For example, a cross hair could be used by the operator **300** to indicate a spot where a local reading needs to be expressed as a value. For example, the operator **300** may move the sensor until the cross hair coincides with a specific position on the object **200** and activates a function. In some embodiments, the LPD **110** may then project the XYZ deviations of the surface at the position of the cross hair by displaying a fly-out window with the X, Y, Z and/or normal deviations.

For complex object geometry, areas with difficult visibility may be more easily visualised by changing the alignment of the LPD **110**. The projection of information onto the object **200** can eliminate the need to read that information from a computer screen. The optimal alignment can be performed automatically and/or intuitively, for example by re-positioning the LPD **110** and/or by pointing the LPD **110** to the concerned surfaces of the object.

The projection from the LPD **110** may comprise a projection beam **114**, which is in fixed relation to the light-emitting end of the LPD **110** as shown in **FIG. 2A**. Alternatively or in addition, the angular direction of the projection beam **114** may be adjusted as shown in **FIG. 2B**. In a preferred embodiment of the invention, the LPD **110** projects the projected image **112** within a projection beam **114**, and the LPD **110** is configured to allow spatial adjustment of the direction of the projection beam **114**. For example, the adjustment unit **130** may steerably control a mirror incorporated into the LPD **110**.

The direction **800** of the projection beam **114** may be represented as the azimuth (or azimuth angle) **810** and elevation (or elevation angle) **820** of the object **200**. Azimuth **810** refers to the angular position of the object **200** relative to a vertical plane (projected perpendicularly onto a horizontal plane), while the elevation **820** refers to the angular position of the object **200** relative to a horizontal plane (projected perpendicularly onto a vertical plane), as illustrated in **FIG. 7**. The reference horizontal and vertical planes may be defined by the LPD **110** itself, or by the spatial relationship between the LPD **110** and the PMD **120**.

In one embodiment of the invention, the projection system **100** further comprises:

- the position-measurement device **120**, PMD, configured to determine the position and/or the orientation of the LPD **110** or the PMD **120** in relation to the object **200**.

The position-measurement device or PMD **120** is any device known in the art for measurement of the position and/or orientation of the LPD **110** in relation to the object **200**. The PMD **120** typically has a measurement volume in which the LPD **110** is disposed. The LPD **110** is essentially observed by the PMD **120**. The PMD **120** is typically external to the PMD **120**. The LPD **110** may be mechanically connected to the PMD **120**; such PMD **120** typically has a base end **122** and an effector end **124** connected by one or more interconnected moveable members. The base end **122** of the PMD and an object **200** can be mounted on a solid surface **400** such that there is no relative movement during projection. The effector end of the PMD **120** may be provided with a coupling for dismountable attachment to the LPD **110** and optionally to a dimensional acquisition device. The LPD **110** is preferably mechanically attached to the effector end **124**. The mechanical attachment is preferably rigid. The position of the effector end and hence of the LPD **110** may be determined from angles and/or displacements arising between the moveable members, while the LPD **110** is moved. The moveable members may be arranged in a kinematic chain having rotary encoders at each joint, for instance. Examples of such a PMD **120** include an articulated arm, a localizer, a coordinate measuring machine (CMM), or a coordinate measuring arm (CMMA) **121**. The PMD **120** may be robot, such as a robot coordinate measuring arm (Robot CMMA) as described, for instance, in WO 2004/096502.

Alternatively, the PMD **120** may comprise an overseeing device **150**, such as a camera, configured to optically track the LPD **110**; the LPD **110** may be disposed with one or more reflective or light-emitting markers which are detected by the camera **150**, from which the position and/or orientation of the LPD **110** can be determined. Tracking of the position and/or orientation of an object by an overseeing device **150**, such as a camera, is known in the art, for instance from WO 98/36381 and WO 03/067546. Such a camera **150** is typically provided with a lens that focuses light onto a two dimensional active pixel sensor (*e.g.* a CMOS or CCD sensor) for capture of the image of the LPD **110** or reflective or light-emitting markers thereon. The camera **150** is typically disposed in fixed relation to the object **200** and arranged so that the LPD **110** remains within the field of vision for the range of its movements. The position in space of the LPD **100** may be determined from its position the within the captured frame or on the active pixel sensor.

Information as to the orientation of the LPD **110** may be obtained when there are three or more markers on the LPD **110**, and the distances between the markers are known. The positions of said markers may be measured in two dimensions by means of the camera **150**. In particular, the co-ordinates of the position of each of the markers may be determined according to two preferably perpendicular directions in a plane standing at right angles to the optical axis of the camera **150**. Next, the actual three-dimensional position of the markers is calculated on the basis of the positions of the markers, thus measured in a two-dimensional manner, and the real distance between each of these markers. In the case of a two-dimensional position measurement, one measures the position of said markers in a plane standing at right angles to the optical axis of the camera **150**. By taking into account, however, that these markers have a fixed position in relation to one another, the co-ordinate of each of the markers is calculated on the basis of the real spatial distances between these markers and their co-ordinates measured in a two-dimensional manner, according to the direction of the optical axis of the camera **150**. This calculation is made according to conventional goniometric calculation methods.
Examples of such a PMD **120** includes an optical tracker, a laser tracker probe, a K-series camera (manufactured by NikonMetrology), and an iSpace system (manufactured by NikonMetrology). In some embodiments, the PMD **120** comprises a local inertial system, such as an accelerometer or a gyroscope.

As mentioned earlier, the PMD **120** is configured to determine the position and/or the orientation of the LPD **110** in relation to the object **200**. Preferably, the PMD **120** is configured for measuring all 6 degrees of freedom (DOF), for example 3 DOF for position and 3 DOF for orientation, also referred to as 6DOF, of the LPD **110** in relation to the object **200** In a preferred embodiment of the invention, the PMD **120** is configured to determine the 6 degrees of freedom, 6DOF, related to the position and the orientation of the LPD **110** in relation to the object **200**.

As mentioned earlier, the adjustment unit **130** is configured to maintain the projected image **112** essentially static relative to the object by mathematically transforming the image and/or by steering the projection beam **114**. The adjustment unit **130** according to the invention may comprise mechanical components, optical components, electronic components (such as a processing device **131**), or a combination thereof. The adjustment unit **130** may be incorporated partially or entirely into the LPD **110**.

In an embodiment, the adjustment unit **130** comprises one or more mechanical and/or optical components, optionally comprising one or more steering mechanisms. A non-limiting example of such an adjustment unit **130** comprises a steerable mirror. **FIGs. 8A** and **8B** illustrate an LPD **110** wherein the adjustment unit **130** comprises a steerable mirror **135**. In **FIG. 8B**, the orientation of the mirror **135** is adjusted to displace the projected image downwards compared with **FIG. 8A**. The adjustment unit **130** may comprise one or more mechanical components, preferably one or more joints, such as a universal joint, ball joint, or a gimbal. The adjustment unit **130** may comprise one or more steering mechanisms, such as a servo, a linear motor, or a magnetic steering mechanism. The adjustment unit **130** may comprise one or more optical components, such as mirrors, lenses, prisms.

In an embodiment, the adjustment unit **130** comprises a processing device **131**, configured to receive signals from the PMD **120**, process them and output signals to the LPD **110**, preferably wherein the processing device **131** is configured to control the position of the projected image **112** on the object **200**. The processing device **131** may perform transformations to the image, or may steer mechanical and/or optical components, or may perform a combination of both.

In an embodiment, the processing device **131** may use mathematical models to transform the position and/or shape of the image **112**. The processing device **131** may also comprise mathematical models to transform the shape of the projected image **112**. In an embodiment, the adjustment unit **130** also comprises a mechanical steering element, steered by the processing device **131**. The adjustment of the image **112** may be performed electronically (*i.e.* by transformation of the image), mechanically/optically, or through a combination of both.

As mentioned earlier the projected image **112** may be projected within a static projection beam **114**, in which case the image area **112** relative to the beam area **115** is small. That the image area **112** is smaller than the beam area **115** allows a window for movement of the projected image **112** within the bounds of the projected beam area **115** without the need to steer the projected beam. In such cases, the processing device **131** may use one or more mathematical models to transform the position and/or shape of the image **112**.

The signals from the PMD **120** may specify a transform R_po (position and rotation) with reference to the object **200**. The image **112** on the object may be described by a transform R_io (position and rotation) with reference to the object **200**. The image **112** on the object **200** is formed by the projection on the object **200**, which is influenced by the transform R_po, and the image changes transform R_im (position, rotation, scaling, deformation) in the LPD **110**. To maintain the image **112** stable on the object **200**, the image R_im is adapted to compensate for the change in R_po, which can be performed by matrix manipulations and matrix calculations.

The projection on the object **200** can be described by matrices. If the object **200** is non-flat, this may also be described by functions. In all cases, it may be assumed that the observer view point (user) is near the LPD **110**. If the observer view point is at a significantly different location, an extra deformation transform may be added to account for the new perspective by the observer.

For example, the processing device **131** may perform the following steps:

- calculating the image to be seen by observer, based on R_io;
- calculating the transformed image needed on the object **200**, using the observer R_obs (position and rotation relative to the object **200**), wherein this calculating step may involve scaling, rotation, deformation, preferably wherein R_obs is identical or almost identical to R_po;
- optionally, for a non-flat object **200**, adapting the image to compensate for the curvature of the surface of the object **200**, wherein for simple deformations this step may be performed through functions, and wherein for more complex deformations, this step may be performed through ray tracing; and
- from the image on the object, calculating the image in the LPD using the inverse of R_po.

Alternatively or additionally, the projected image **112** may be moved using a steerable projection beam **114**. The image area **112** may be smaller or the same size as the beam area **115**. Movement of the projected image **112** relative to the object surface **202** to maintain a static appearance is achieved by steering the projection beam **114** (*e.g.* **FIG. 2B**) and/or by moving the projected image **112** within the bounds of the projected beam **area 115** (*e.g.* **FIG. 2A**). In case of such mechanical steering element, such as a steerable mirror, a new transform R_mirror may add extra flexibility.The same steps and matrix equations as discussed above may be used, but with an extra transform. In a preferred embodiment, the correction can be performed by moving the image as described above for high frequency movements (with small amplitude), while low frequency adaptations (with larger amplitude) are performed with additional use of a steerable mirror (R_mirror).

Preferably, the processing device **131** tries to keep the image in the middle of the LPD **110**, by adapting the mirror position.

As mentioned earlier, the projected image **112** may be adjusted so that the image **112** has an essentially static appearance in relation to the object **200**, responsive to movement of the LPD **110** detected by the PMD **120**. In such an embodiment, the projected image **112** remains (essentially) stable on the object **200**, even if the LPD **110** is (constantly) moving. Adjustment of the projected image **112** may comprise adjustment of the position of the projected image **112** and/or adjustment of the orientation of the projected image **112**. Adjustment of the image may comprise one or more of translating, rotating, tilting, resizing and skewing the projected image **112**.

In an embodiment, the projected image **112** is adjusted to compensate for the deformation of the projected image **112** by a curved (non-flat) surface of the object **200**.

In an embodiment, the projected image **112** is adjusted using ray tracing (using the reverse light path) from the desired image on the object 200, back to the LPD **110**. The desired image in the LPD **110** is what would be seem by a camera (image sensor) at the same place as the LPD **110**, when the desired image would be the object **200**. Such a ray tracing technique may be performed by commercially available software compiled in an adjustment unit **130** comprising a processing device **131**. If the position and orientation of the observer and LPD **110** are substantially different, a correction may be applied, based on the difference between location and orientation between observer and LPD. Depending on the actual object **200** and geometrics, ray tracing may not always be possible, for example due to occlusion of certain parts of the object **200**.

The object **200** may be fixed relative to the measurement reference frame of the PMD **120** during projection, for example on a surface **400**. Alternatively, the object **200** may not be fixed relative to the measurement reference frame of the PMD **120** during projection. An overseeing device that observes both the object **200** and the PMD **120** or a point in fixed relation to the PMD may then provide information on the movement of the object **200** relative to the PMD **120**. The overseeing device **150** may comprise a camera configured to optically track the object **200** relative to the PMD **120**. For example, the object **200** and optionally the PMD **120** may be disposed with one or more reflective or light-emitting markers which are detected by the camera **150**, from which the position and orientation of the object **200** can be determined.

The projection system **100** according to the invention may be used to project an image **112** onto a specific area of an object **200**, or onto a specific area of a target surface of an object **200**. The PMD **120** is configured to determine the orientation of the LPD **110** in relation to the object **200**. Preferably, the projection system **100** uses data obtained from the PMD **120** to derive the relative position and/or orientation of the LPD **110** with respect to the object **200**. This data may be used to adjust the projected image **112** to provide a stable image **112** projected on the corresponding surface area of the object **200** during movement of the LPD **110**.

If the position and/or orientation of the PMD **120** relative to the LPD **110** is known, or can be determined, then the position of the LPD **110** in relation to the object can be determined from the position of the PMD **120** in relation to the object. In a preferred embodiment, the PMD **120** is mechanically attached to LPD **110**. The position and/or orientation of the LPD **110** relative to the object **200** can then be easily derived from the position and/or orientation of the PMD **120** relative to the object **200**.

In a preferred embodiment, the PMD **120** and LPD **110** are mechanically connected, preferably rigidly mechanically connected, preferably at the effector end **124** of the PMD **120**. In such an embodiment, the relation (or calibration) between the PMD **120** and LPD **110** may be readily determined and set for at least part of the lifetime of the system without need for further calibration. The calibration may be set at the factory. Once the calibration is known, it does not need to be re-calculated for each use; however, it will be appreciated that a calibration may be performed periodically *e.g.* on a monthly or yearly basis as required.

In a preferred embodiment of the invention, the projection system **100** further comprises a dimensional acquisition device **140**, DAD. Preferably, the DAD **140** is configured to acquire dimensional data of the object **200**. Such a system **100** incorporating a DAD **140** is more typically known as a metrology system, insofar as it is employed to produce a stream of data relating to the dimensions of an object.

As used herein, the term “dimensional acquisition device” or DAD **140** comprises any device that is configured to acquire dimensional data of the object **200**, preferably 3D dimensional data of the object **200**. The DAD typically outputs data signals that may be electronic or optical. For example, the DAD **140** may comprise a metrology receiver. In some embodiments, the DAD **140** comprises a plurality of metrology receivers. Examples of DADs **140** include a non-contact probe, an optical non-contact probe, a laser scanner, a laser profiler, a contact probe, and the like.

In an embodiment, the DAD **140** is mechanically attached to the LPD **110**. Preferably, the DAD **140** is rigidly mechanically attached to the LPD **110**. Preferably this mechanical attachment provides a fixed relation between the DAD **140** and the LPD **110**. In an embodiment, the DAD **140** is mechanically attached to the PMD **120**, preferably to the effector end **124** of the PMD **120**. In a preferred embodiment, both the DAD **140** and the LPD **110** are mechanically attached to the effector end **124** of the PMD **120**. In an embodiment, the PMD **120** is configured to determine the orientation of the DAD **140** in relation to the object. **FIG.1** depicts an embodiment wherein the DAD **140** and the LPD **110** are mechanically attached to the PMD **120**, but wherein the DAD **140** and the LPD **110** are movable in relation to the object **200**.

In an embodiment, the DAD **140** and LPD **110** are two separate units, and are configured to minimize perturbation of the DAD **140** by the projected image **112**. For example, when the DAD **140** is a Laser Scanner, it may be set to project a specific light color and may comprise specific light filters to prevent the projected image **112** from influencing the data acquisition via a light stripe **142**. In another example, the LPD **110** and DAD **140** may be synchronized such that during each flash of a Laser Scanner, no image is projected.

The DAD **140** may be used to align the projection system **100** with the object **200**. The DAD **140** may additionally or alternatively be used to acquire dimensional data of the object **200** simultaneously with projecting an image **112** onto the object **200**. In an embodiment, the LPD **110** is synchronized with a laser scanner DAD **140**. The LPD **110** projects as part of the image a line such as a line stripe projector. The image projected by the LPD **110** may convey feedback information to the user responsive to dimensional acquisition by the DAD **140**.

FIG.5 depicts a chart showing the relationships between a DAD **140**, an LPD **110**, a PMD **120** (comprising a CMMA **121**) and a processing device **131** and signals that may be sent between them. The DAD **140** in **FIG. 5** may be a Laser Scanner **740**, comprising a light detector **742** and a laser source **744**. The LPD may comprise a steering mechanism **710** connected to a light source **714** and an imager **712**. The processing device **131** may be located in a number of places. In an embodiment, the processing device **131** is in a separate box (for example a PC), for example through a wired or wireless connection. In a preferred embodiment the processing device **131** is located in or near the LPD **110**, and preferably communicates through wireless signals. Sending 6DOF to the LPD **110** needs much less bandwidth than sending a video stream. In an embodiment, the mainly static part of the image (before motion related processing) is controlled by a PC. The processing device **131** may comprise a DSP controller **730** which may control a field-programmable array (FPGA) **732** and/or a peripheral interface **734**, for example a serial peripheral interface bus (SPI). The processing device **131** which may communicate through Bluetooth **731**, WiFi **733** and/or a connector **735**.

FIG. 6 shows the information that may be transferred between several components. An optional DAD **140** (in this case a laser scanner) may transmit surface information to a processing device **131**, which forms part of an adjustment unit **130** (in this case a PC). The DAD **140** may have an internal CPU and FPGA to generate the surface info. The DAD **140** may also provide synchronization to a PMD **120**. The PMD **120** may comprise its own electronics, possibly including an FPGA. The PMD **120** provides position location information, such as 6DOF to the processing device **131**. The processing device **131** may have its own electronics to perform image processing and communication. The image processing may be FPGA, DSP or GPU based, or based on a combination thereof. The processing device **131** may then send a processed image, steering position info, or a combination thereof to an LPD **110**. The LPD **110** may have its own electronics to control the steering (for example through a steerable mirror) if present and to control the imager.

In order to take the position of the object **200** with respect to the projection device **100** into account, an alignment procedure is preferably carried out, prior to the actual projection functions. Alignment procedures are known in the art, and may comprise the use of a DAD **140**, such as tactile measurement, scanning and best fit of the object **200**, and/or scanning and best fit of any type of reference features that are connected to the object **200**. Preferably, a projected image **112** is generated that takes into account the line of sight restrictions of the visibility of the surface of the object **200** from that specific position.

In some embodiments, the DAD **140** comprises one or more probes. The probes may be any kind of probe, such as a non-contact probe, for example a light probe configured for emitting a light stripe **142**, or a contact probe, for example that utilizes a tactile member. The probe can be configured to capture probe data, preferably dimensional data of the object. Preferably, the probe data that contains dimensional data of the object may be used to adjust the projected image **112**, for example by the processing device **131**.

Types of non-contact probe include a scanner, preferably a laser scanner. Suitable laser scanners are commercially available from *e.g.* Nikon Metrology NV, Faro Technologies Inc, and Perceptron Inc. The probe may be provided with a coupling member configured for attachment to a robot or utilized for hand-held, manual data acquisition.

Alternatively, the probe may be a radiation meter, temperature probe, thickness probe, light-measurement probe, or profile measuring probe. The thickness probe may employ ultrasound, or ionizing radiation.

The type feedback information provided by the projected image can vary; some examples follow. The dimensional data of the object **200** may comprise information on the shape and/or curvature of a target surface of the object **200**. The target surface may be an essentially flat surface or a curved surface. In some embodiments, the dimensional data of the object **200** comprises information on displacement of the target surface of the object **200**. In some embodiments, the dimensional data of the object **200** comprises information on stress on the target surface of the object **200**.

In some embodiments, the DAD **140** is configured to create a surface representation of the object **200**. Non-limiting examples of suitable surface representations include a set of points, a point cloud, a set of triangles (triangle mesh), and a set of polygons (a polygon mesh).

In a preferred embodiment of the invention, the projection system **100** is configured to adjust the appearance of the projected image **112** responsive to the dimensional data of the object **200**.

In some embodiments, a reference model is available of the object **200**. For example, in an inspection application, this reference model can comprise a computer-aided design, CAD, model of the object **200**. In an embodiment, the geometrical deviations between (the surface of) the object **200** and the reference model, preferably a CAD model, can be derived from the data acquired by the DAD **140**. Preferably, these deviations are subsequently displayed onto the object **200** by the LPD **110**, for example as a color coded pattern. Surface deviations can also be displayed as magnified color coded vectors. In an embodiment, such a pattern is generated based on a comparison of the measured point cloud to the nominal surface of the object **200**. The deviations can be projected onto the object **200** during and/or after the measurement by the DAD **140** takes place.

The projection system **100** comprising a DAD **140** can also be used for dimensional verification of geometrical features of the object **200**, for example round holes, slot holes, edges, and fixture elements. In an embodiment, the deviations of such geometrical features are calculated and displayed as textual values, for example shown in fly-out windows that point to the concerning area on the object **200**.

In an embodiment, the representation of deviations of the geometry of an object **200** enables the operator **300** to conclude on the required additional process steps, if any, to get the product within its desired specifications. This can be obtained by modifying the product itself or by modifying the process parameters in a manufacturing facility.

In some embodiments, the projected image **112** identifies the surface area of the object **200** that has already been scanned by the DAD **140**. In a preferred embodiment, the projected image **112** indicates the quality (*e.g.* local quality) of the scan by the DAD **140**. In some embodiments, for example when the DAD **140** comprises a manual laser scanner, the point coverage during the scanning can be projected by the LPD **110** in order to guide the operator **300** to areas where the point density is not yet sufficient. In a preferred embodiment, the projected image **112** indicates the quality of the scan by the DAD **140** and provides instructions to the user.

In preferred embodiment of the invention, the processing device **131** is further configured to:

- receive dimensional data of the object **200** from a dimensional acquisition device **140**, DAD, configured to acquire dimensional data of the object **200**; and
- adjust the projected image **112** responsive to the dimensional data of the object **200**.

Alignment of the projection system **100** with the object **200** can be performed in several ways, depending on whether the projection system comprises a DAD **140** and/or a utilises a reference model of the object **200**. The reference model is a mathematic representation of the object **200** (*e.g.* a computer-aided design model of the object). Some possible different configurations are discussed below.

In an embodiment, the projection system **100** comprises an LPD **110** and a PMD **120**, but does not utilise a reference model and does not use a DAD **140**. The system can be programmed to present information (in one or more information zones) to the user based on the LPD **110** position as given by the PMD **120**. The PMD **120** may mainly be used for position determination. The positions of the information zones can be fixed, or can be dependent on the actions of the user. For example, the user can indicate the four corners of the work zone, similar to touch screen calibration. The LPD **110** could project for example a cross-hair, and the user would point to each calibration point and push a button to calibrate.

In an embodiment, the projected image **112** comprises information for the user, such as instructions. The instructions may be updated as the LPD **110** is moved.

In an embodiment, the projection system **100** comprises an LPD **110**, a PMD **120**, and utilises a reference model, but no DAD **140**. To correlate the reference model with the position of the object **200,** the user can be instructed by simple instructions projected by the LPD **110** to aim the LPD **110** at specific points of the object **200**. For example, a crosshair or a part of the reference model may be projected, which is the user then aligns with the actual object **200**; once they are aligned, the user may confirm by pressing a trigger. The number of calibration points may depend on the required accuracy.

In an embodiment, the projection system **100** comprises an LPD **110**, a PMD **120**, and a DAD **140**, but does not utilise a reference model. Without a reference model, the user preferably scans enough of the object to provide an internal representation of the object **200**. This internal representation can then be used similarly to the reference model for image correction. The quality of image projection may gradually improve as more information of the object **200** is acquired through the DAD **140**.

In an embodiment, the projection system **100** comprises an LPD **110**, a PMD **120**, and a DAD **140**, and a reference model. The process for alignment is similar to the case as described for the situation without a DAD **140**, but the DAD **140** can now be used as a higher performance calibration device, thereby improving the accuracy of alignment, independent from the user's ability to align a crosshair or image with the object **200**. Using the DAD **140** to measure a few parts of the object, provides the possibility to align the reference model and to immediately improve image projection quality for the full object **200**, and not only the parts that have already been scanned. In addition, the reference model can be used to calculate differences between the actual object **200** and the reference model and show these in the projected image **112**.

In an embodiment, the processing device **131** is configured to:

- receive data from the PMD **120** as to the position and/or orientation of the LPD **110** relative to the object **200**;
- optionally, receive dimensional data acquired from a DAD **140**;
- optionally, receive a reference model, preferably a computer aided design, CAD, model, of the object **200**;
- adjust the projected image of the LPD **110** responsive to the data received from the PMD **120**, optionally also responsive to the data received from the DAD **140**, optionally also using the reference model to calculate the adjustment.

In another embodiment, the processing device **131** is configured to:

- receive a reference model, preferably a computer aided design, CAD, model, of the object **200**;
- receive data from the PMD **120** as to the position and/or orientation of the LPD **110** relative to the object **200**; and
- adjust the projected image responsive to the data received from the PMD **120** using the reference model to calculate the adjustment.

In some embodiments, the adjustment by the processing device **131** uses an inspection program. In a preferred embodiment, this inspection program is linked to a DAD **140**. An example of an inspection program suitable for the invention is Focus Inspection, commercially available by Nikon Metrology.

The processing device **131** may be provided as a single unit, or a plurality of units operatively interconnected but spatially separated. The processing device **131** may be integrated fully or partly into the housing of the PMD **120** or into a single housing that contains both the PMD **120** and LPD **110**. Where there is partial integration, it is meant a separate unit outside the housing may contain part of the electronics of the processing device **131**. Alternatively, the processing device **131** can be housed fully outside the housing of the PMD **120** and LPD **110** or outside the single housing that contains both the PMD **120** and LPD **110** (*e.g.* as a dedicated processing unit, as a laptop, desktop computer, smartphone, tablet device). When the processing device **131** is housed fully outside or is only partly integrated, interconnections between devices may utilize a cable or wireless connection (*e.g.* Bluetooth, Wifi, ZigBee or other standard). Different connections **132**, **134** and/or **136**, may be used for connecting the processing device **131** with the LPD **110**, the PMD **120** and/or the DAD **140** respectively. It will be appreciated that the sub-processors and/or processing device **131** may also perform other tasks such as synchronization, system control, power management, I/O communication and the like typically associated with digital systems. The processing device **131** may also operate with other devices (both hardware and software). The processing device **131** may also perform adjustments of and/or transformations to the projected image **112**, for example to rotate, translate, tilt, skew or re-size the projected image **112**.

In an embodiment, the processing device **131** comprises one or more specific functionalities. These functionalities may be triggered by pointing the LPD **110** to a specific area (this may be somewhat similar to a traditional computer mouse pointing a cursor to a specific area of the computer screen). For example, pointing the LPD 110 to a region of the workspace, may activate a display of the status, or may activate a help display, or may activate a the display of a set of instructions.

One or more elements of the projection system **100**, for example the LPD **110**, the PMD **120**, the processing device **131** and/or the DAD **140** may be provided in a plurality of separate housings, or preferably may be integrated into a single housing. A single housing offers convenience of portability and size. Additionally, the housing or an internal chassis therein may provide a rigid fixture for the LPD **110** and the PMD **120**, optionally also for the DAD **140**, to hold them in a fixed relative spatial alignment for optimal performance. In a preferred embodiment of the invention, the LPD **110** is portable, preferably the LPD **110** is handheld.

For specific user interface functionality a trigger button and one or several function buttons may be required to activate and trigger specific functions (e.g. the indication of a spot to generate a text window with the deviations in that indicated spot).

The projection system **100** according to the first aspect of the invention and preferred embodiments thereof provide one or more of the following advantages:

- the possibility to display complex process information, which may be difficult to interpret from a computer screen;
- elimination of the requirement of a computer screen or the requirement to have constant visibility of a computer screen for process feedback;
- reduction of operator **300** training requirement when interpretation of process steps is simplified;
- reduction of operator **300** training requirement when each process step can be displayed sequentially for operator **300** guidance, eliminating the need to memorize all process steps;
- gain in operation time through constant focus of the operator **300** onto the object **200** without the need to move to or glance at a computer to interpret the information displayed on the computer screen;
- gain in operation time through an increase of process speed by the projection of operator instructions to perform the manual process, together with the indication of which area these instructions related to;
- quality improvement through a simplification of the process feedback display enables the interpretation of the info, suitable to a large group of lower skilled operators;
- quality improvement through reduction of the risk of process steps being skipped or performed in wrong order;
- cost reduction through reduction of the number of iterations involved in the process to reach a certain quality level;
- ability to display information on objects with complex geometry; and/or
- elimination or reduction of shadow formation.

An exemplary operation **500** of an adjustment unit **130** comprising a processing device **131**, as part of the projection system **100**, is described below with reference to the flowchart of **FIG. 3**.

1) In a first stage **510**, the LPD **110** is aligned with the object **200** to obtain a starting point.
2) In a second stage **520**, a change in LPD **110** position and optionally orientation is measured using the PMD **120**.
3) In a third stage **560**, the projected image **112** is adjusted based on the change in LPD **110** position and optionally orientation measured in the second stage.

The second stage and the third stage may then be iterated **565**, preferably in real-time.

An exemplary operation **600** of a processing device **131**, as part of the projection system **100** comprising a DAD **140**, is described below with reference to the flowchart of **FIG. 4**.

1) In a first stage, the DAD **140** is deployed to measured the object **200**. This first stage may comprise the following steps:
    - receiving **610** a reference model, such as a CAD model, of the object **200**;
    - receiving **612** acquisition data from the DAD **140** concerning the object;
    - comparing **614** the acquisition data to the reference model to determine the spatial relationship between the DAD **140** and the object **200** ; and
    - using the spatial relationship between DAD **140** and LPD **110** to determine the spatial relationship between **616** the LPD 110 and the object

The step of determining the spatial relationship between the DAD **140** and the object **200** assists in an initial set-up of the system **100**. In this embodiment, the DAD **140** is used to measure the object **200**, while the PMD **120** is used to measure the LPD **110**. The presence of a DAD **140** is particularly preferred if no correct model of the object **200** is available.

2) In a second stage, any change in LPD **110** position and optionally orientation is measured by the PMD **120**. This second stage may comprise the following steps:
    - receiving **620** measurement information from the PMD **120** concerning the position and optionally orientation of the LPD; and
    - using the spatial relationship between PMD **120** and LPD **110** to convert **622** the measurement information from the PMD **120** information as to the spatial relation between the to a change in LPD **110** position.

    Parallel to this second stage, the DAD **140** may optionally acquire dimensional data on the object **200** This optional stage may comprise the following steps:
    - receiving **640** dimensional data of object **200** from DAD **140**; and
    - comparing **642** the dimensional data with the reference data received in the first stage.

3) In a third stage, the projected image **112** is adjusted **660** based on the change in LPD **110** position obtained in the second stage, and optionally based on the comparison between dimensional data and reference data as obtained in the optional stage.

The second stage, the optional stage, and the third stage may then be iterated **665** in real-time.

According to a second aspect, the invention encompasses a method for projecting an image **112** onto an object **200** with a projection system **100**, comprising the steps of:

- determining the position and/or orientation of an LPD **110** relative to the object **200**; and
- adjusting the projected image **112** responsive to the position and/or orientation of the LPD **110** relative to the object **200**.

Preferably the projection system **100** is a projection system **100** according to the first aspect of the invention.

In one embodiment of the invention, the position and/or orientation of the LPD **110** relative to the object **200** is detected by a position-measurement device **120**, PMD.

In another embodiment of the invention, the method according to the second aspect of the invention comprises the steps of:

- receiving dimensional data of the object **200** from a dimensional acquisition device **140**, DAD; and
- adjusting the projected image **112** responsive to the dimensional data.

Preferably, the PMD **120** determines the position and/or orientation of the LPD **110** relative to the object **200** in real-time. Such a PMD **120** may be referred to as a 'real-time positional tracker' (RTPT). In a preferred embodiment of the invention, the steps are iterated in real-time.

According to a third aspect, the invention encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, configured for adjusting a projected image **112** on an object, responsive to movement of the LPD **110** of a projection system **100** according to the first aspect of the invention.

The invention also encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, for providing the position and/or the orientation of the LPD **110** in relation to the object **200** of a projection system **100** according to the first aspect of the invention.

The invention also encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, for providing and/or processing the position and/or the orientation of the LPD **110** in relation to the object **200** of a projection system **100** according to the first aspect of the invention.

The invention also encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, for providing and/or processing dimensional data of the object **200** acquired by the DAD **140** according to some embodiments of the invention.

The invention also encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, for adjusting an projected image **112** on an object **200** using a projection system **100** according to the first aspect of the invention.

The invention also encompasses a computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, for projecting an image on an object **200** using the method according to the second aspect of the invention.

CLAIMS

1. A metrology system (100) for dimensional measurement of an object (200) comprising:
   - a light-projection device (110), LPD, configured to project an image (112) onto the object (200);
   - a position-measurement device (120), PMD, having a measurement volume, configured to determine the position and/or the orientation of the LPD (110) disposed within the measurement volume;
   - a dimensional acquisition device (140), DAD, that is an optical non-contact probe rigidly attached to the LPD configured to acquire dimensional data of the object (200);

   and
   - an adjustment unit (130) configured to adjust the projected image (112) to have an essentially static appearance in relation to the object (200), which adjustment is responsive to movement of the LPD (110) detected by the PMD (120);

   wherein the image projected by the LPD (110) conveys feedback information to the user responsive to dimensional acquisition by the DAD (140).

2. The metrology system (100) according to claim 1, wherein the adjustment unit (130) further comprises:
   - a processing device (131), configured to receive signals from the PMD (120), process them and output signals to the LPD (111), wherein the processing device (131) is configured to adjust the position and/or orientation of the projected image (112) to have an essentially static appearance in relation to the object (200).

3. The metrology system (100) according to claim 1 or 2, wherein the DAD (140) is a laser scanner.

4. The metrology system (100) according to claim 2 or 3, wherein the processing device (131) is further configured to:
   - receive a reference model of the object (200);
   - receive data from the PMD (120) as to the position and/or orientation of the LPD (110) relative to the object (200); and

- adjust the projected image responsive to the data received from the PMD (120) using the reference model to calculate the adjustment.

5. The metrology system (100) according to claim 2 or 3, wherein the processing device (131) is further configured to:
   - receive a reference model of the object (200);
   - receive data from the DAD (140) as to the acquired dimensions of the object (200); and
   - adjust the content of the projected image such that the feedback information indicates geometrical deviations between the acquired dimensions of the object (200) and the reference model.

6. The metrology system (100) according to claim 5, wherein the geometrical deviations relate to a dimensional verification of geometrical features of the object (200).

7. The metrology system (100) according to any of claims 5 to 6, wherein the processing device (131) is further configured such that the feedback information includes suggestions of remedial steps to correct the geometrical deviations in the object.

8. The metrology system (100) according to claim 2 or 3, wherein the processing device (131) is further configured to:
   - receive data from the DAD (140) as to the acquired dimensions of the object (200); and
   - adjust the content of the projected image such that the feedback information indicates a local quality of the acquired dimensions of the object (200).

9. The metrology system (100) according to any of claim 5 to 8, wherein the content of the project image is continuously updated during dimensional acquisition.

10. The metrology system (100) according to any of claims 1 to 9, wherein the LPD (110) projects the image (112) along a projection beam (114), wherein the LPD (110) is configured to allow spatial adjustment of the direction of the projection beam (114).

11. The metrology system (100) according to any of claims 1 to 10 wherein the PMD (120) is configured to determine the 6 degrees of freedom, 6DOF, related to the position and the orientation of the LPD (110) in relation to the object (200).

12. Use of a metrology system (100) according to any of claims 1 to 11 for dimensional verification of an object (200).

13. A method for dimensional acquisition of an object, comprising the steps of:
 - providing a light-projection device (110), LPD, configured to project an image (112) onto the object (200);
 - providing a position-measurement device (120), PMD, having a measurement volume, configured to determine the position and/or the orientation of the LPD (110) disposed within the measurement volume;
 - providing a dimensional acquisition device (140), DAD, that is an optical non-contact probe rigidly attached to the LPD configured to acquire dimensional data of the object (200);
 - moving the DAD (110) relative to the object (200) to acquire dimensions of the object (200);
 - adjusting the projected image (112) to have an essentially static appearance in relation to the object (200), which adjustment is responsive to movement of the LPD (110) detected by the position-measurement device (120), PMD,
 - conveying feedback information to the user responsive to dimensional acquisition by the DAD (140), via the image projected by the LPD (110).

14. The method according to claim 13, wherein the steps are iterated in real-time.

15. A computer program, or a computer program product directly loadable into the internal memory of a computer, or a computer program product stored on a computer readable medium, or a combination of such computer programs or computer program products, configured for adjusting a projected image (112) on an object, responsive to movement of the LPD (110) of a projection system (100) according to any of claims 1 to 11, or for performing a method according to claim 13 or 14.

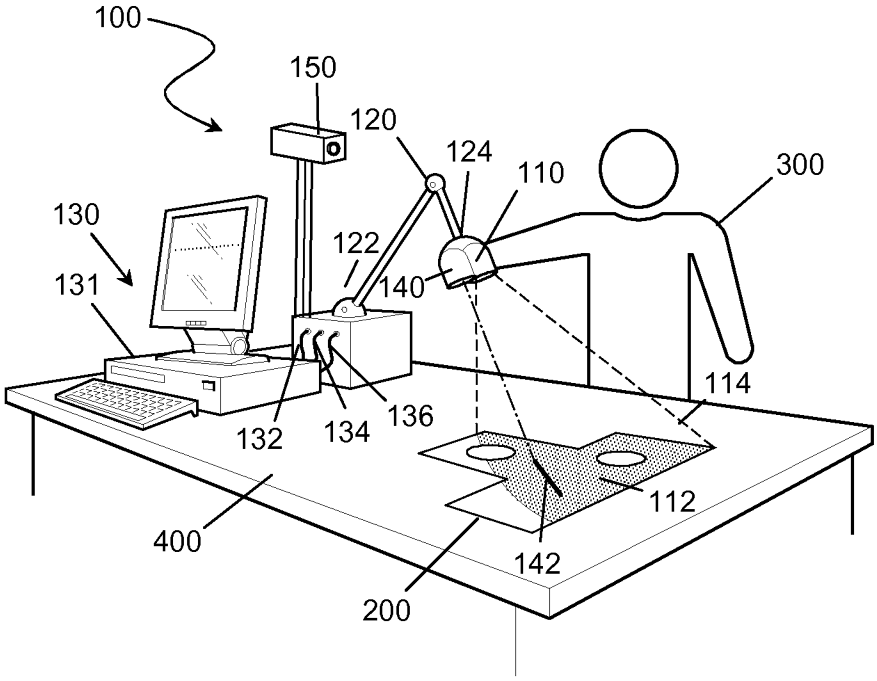

FIG. 1

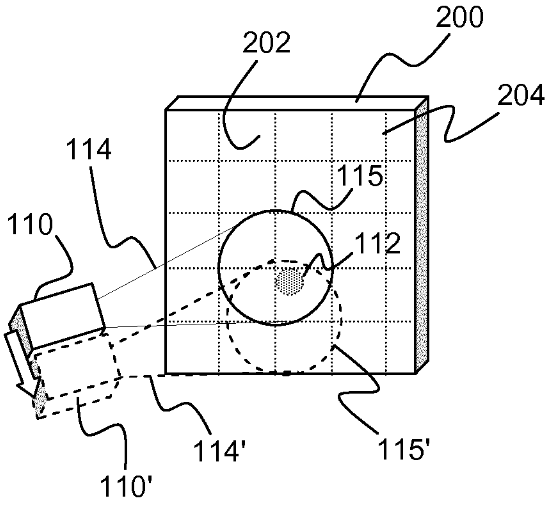

FIG. 2A

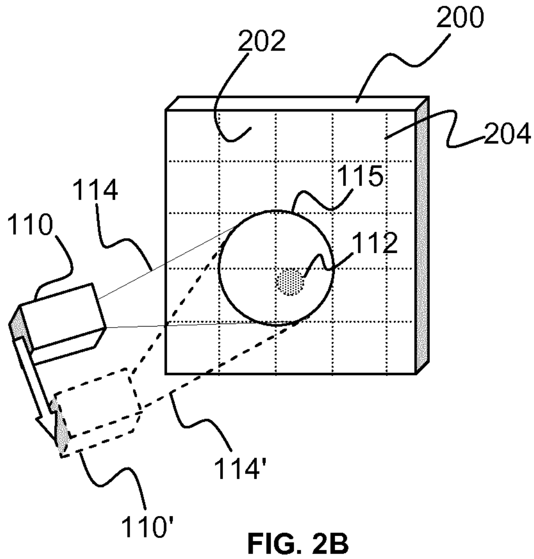

FIG. 2B

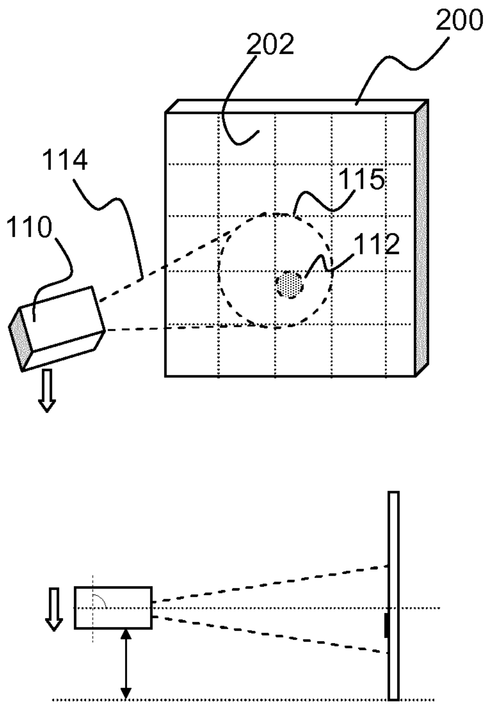

FIG. 2C

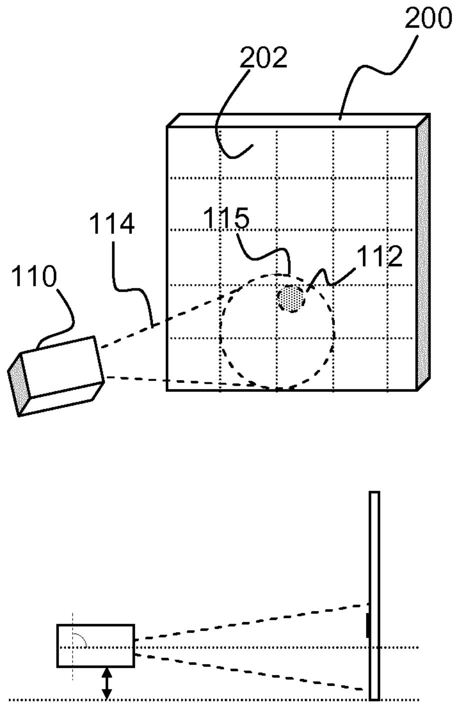

FIG. 2D

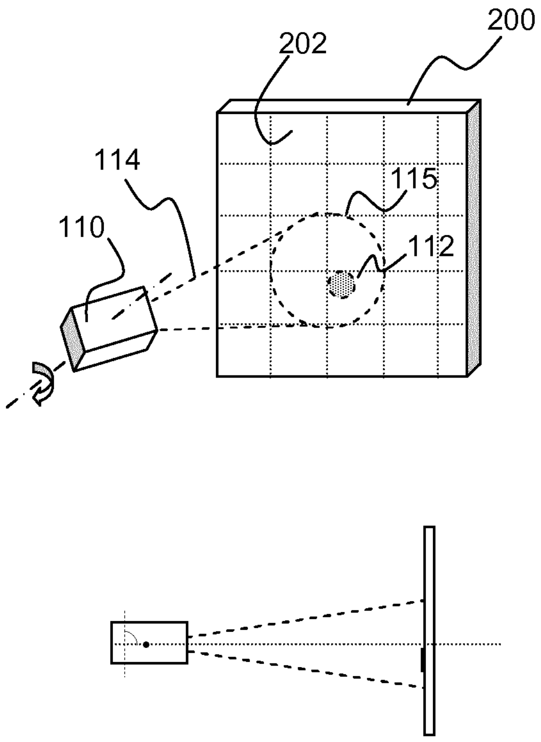

FIG. 2E

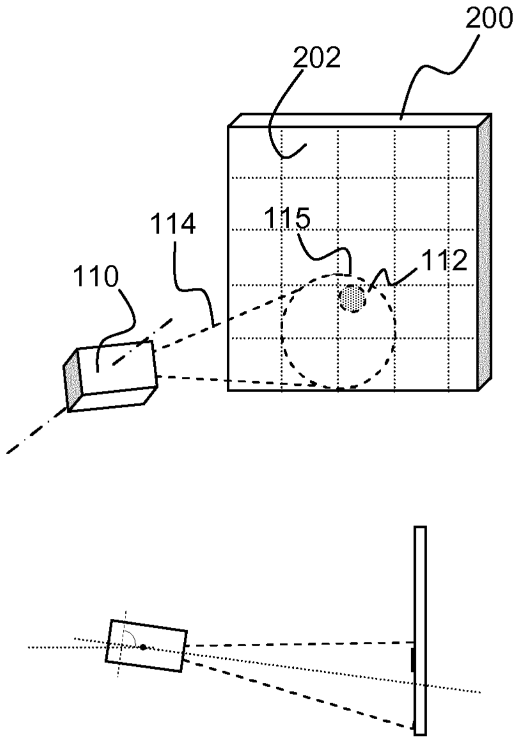

FIG. 2F

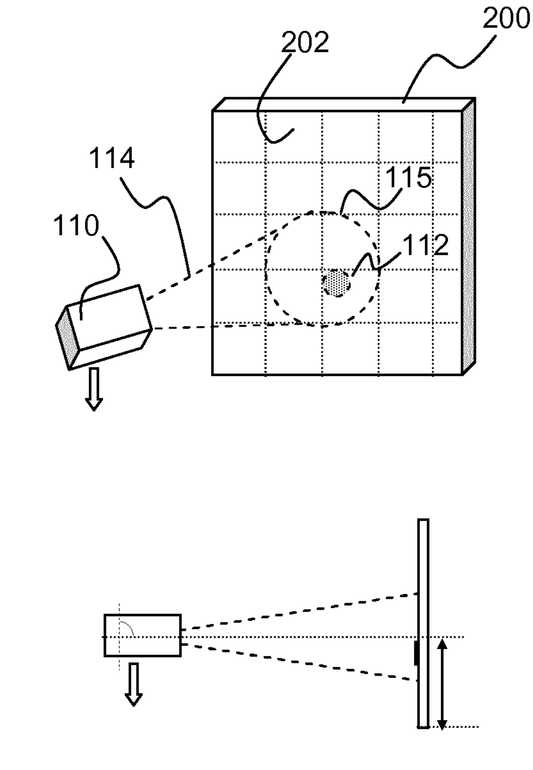

FIG. 2G

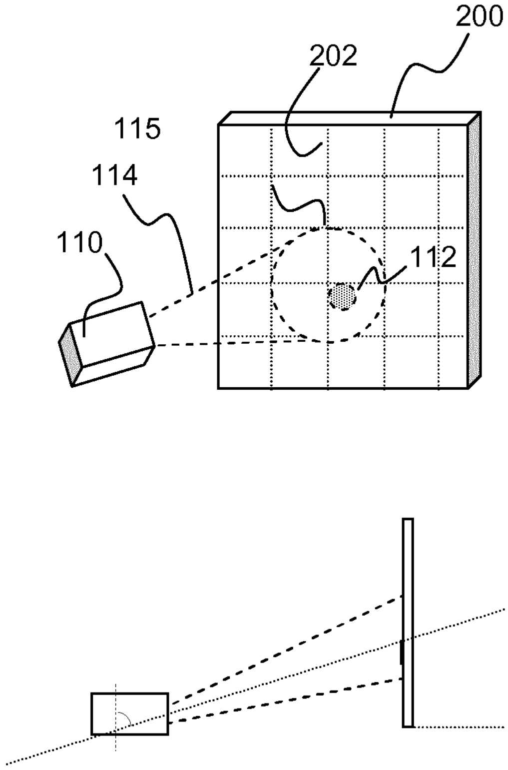

FIG. 2H

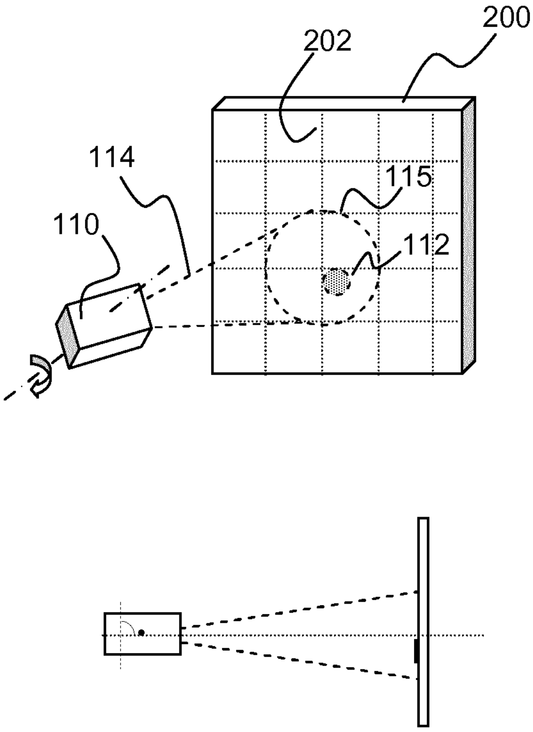

FIG. 2I

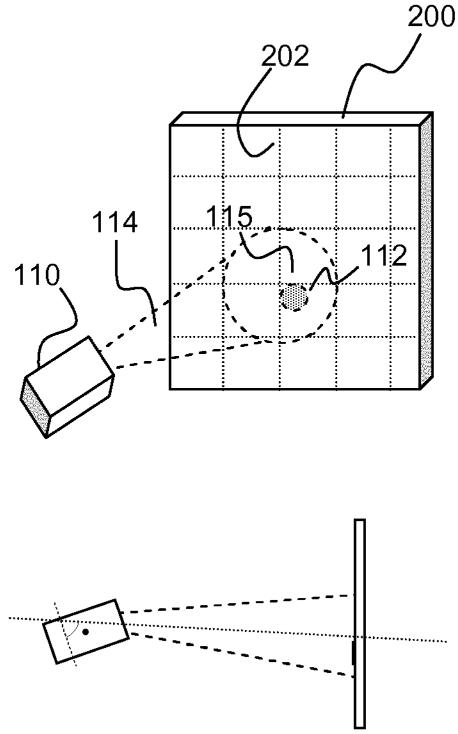

FIG. 2J

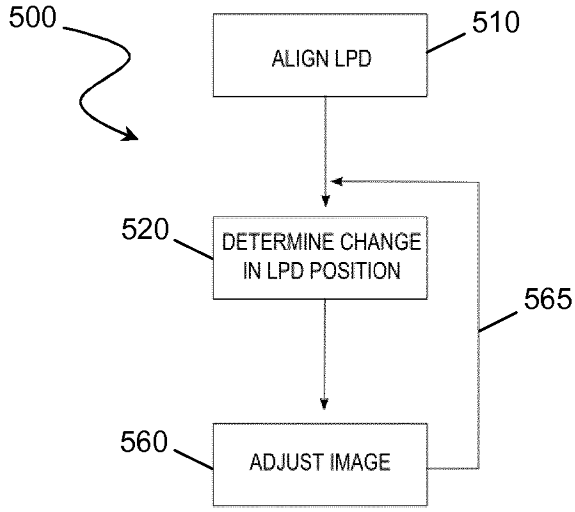
500
ALIGN LPD
510
520
DETERMINE CHANGE IN LPD POSITION
565
560
ADJUST IMAGE

FIG. 3

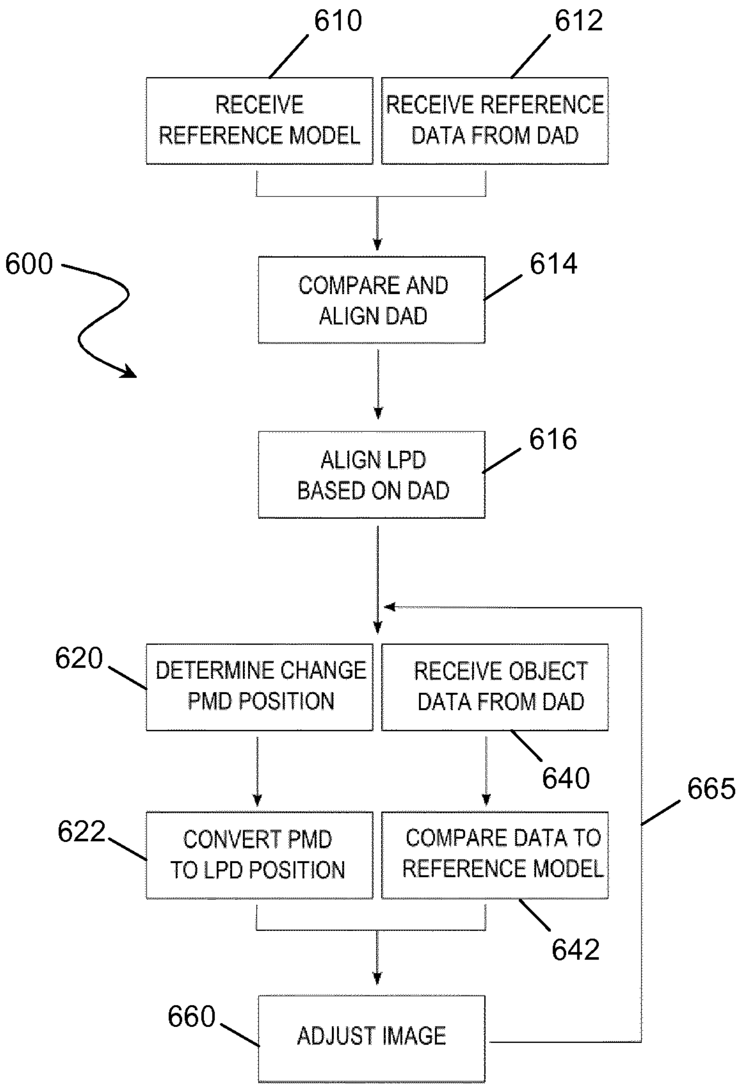
610
612
RECEIVE REFERENCE MODEL
RECEIVE REFERENCE DATA FROM DAD
600
COMPARE AND ALIGN DAD
614
ALIGN LPD BASED ON DAD
616
620
DETERMINE CHANGE PMD POSITION
RECEIVE OBJECT DATA FROM DAD
640
665
622
CONVERT PMD TO LPD POSITION
COMPARE DATA TO REFERENCE MODEL
642
660
ADJUST IMAGE

FIG. 4

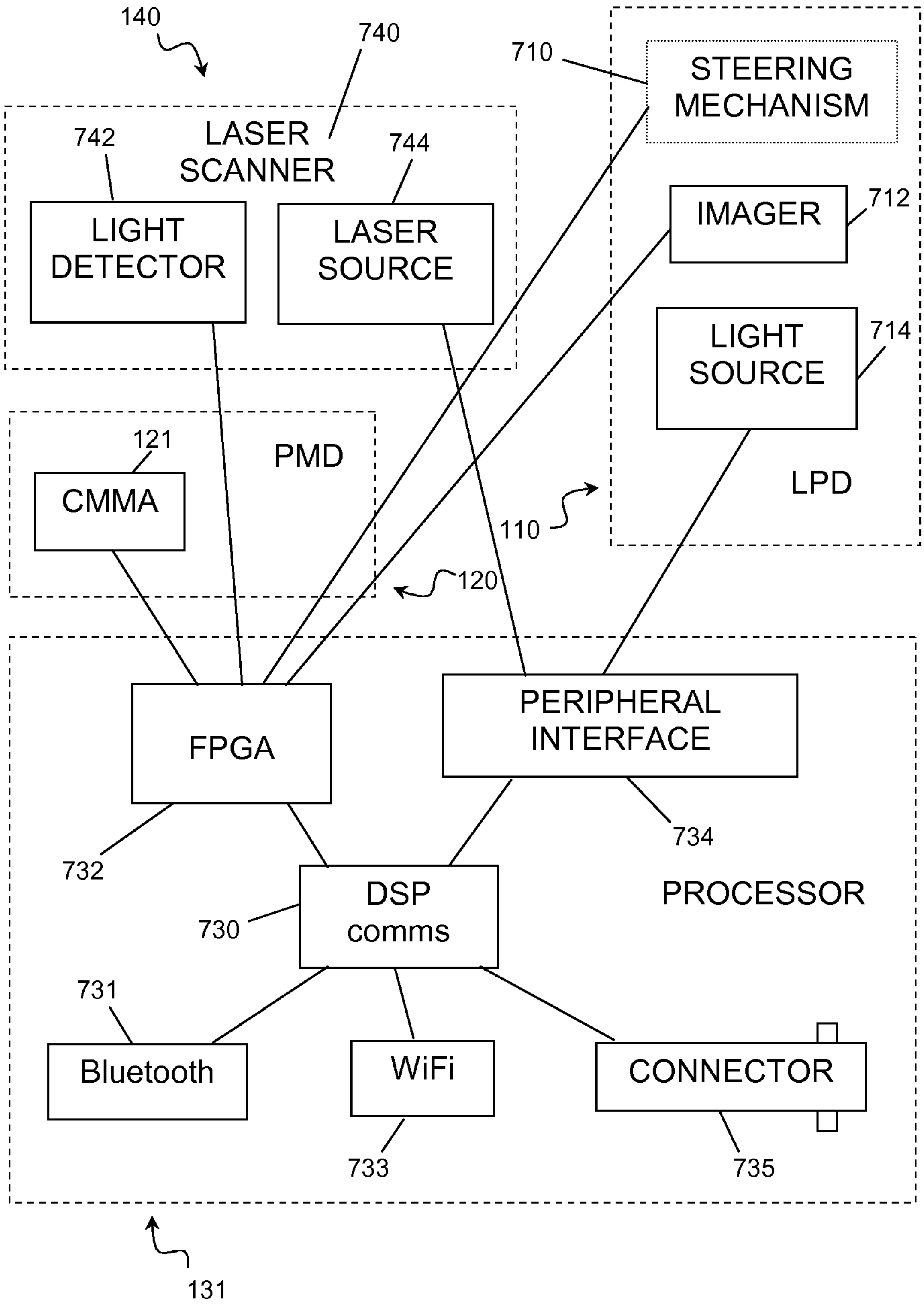
140
740
710
STEERING MECHANISM
742
LASER SCANNER
744
LIGHT DETECTOR
LASER SOURCE
IMAGER
712
LIGHT SOURCE
714
121
PMD
CMMA
LPD
110
120
FPGA
PERIPHERAL INTERFACE
734
732
DSP comms
PROCESSOR
730
731
Bluetooth
WiFi
CONNECTOR
733
735
131

FIG. 5

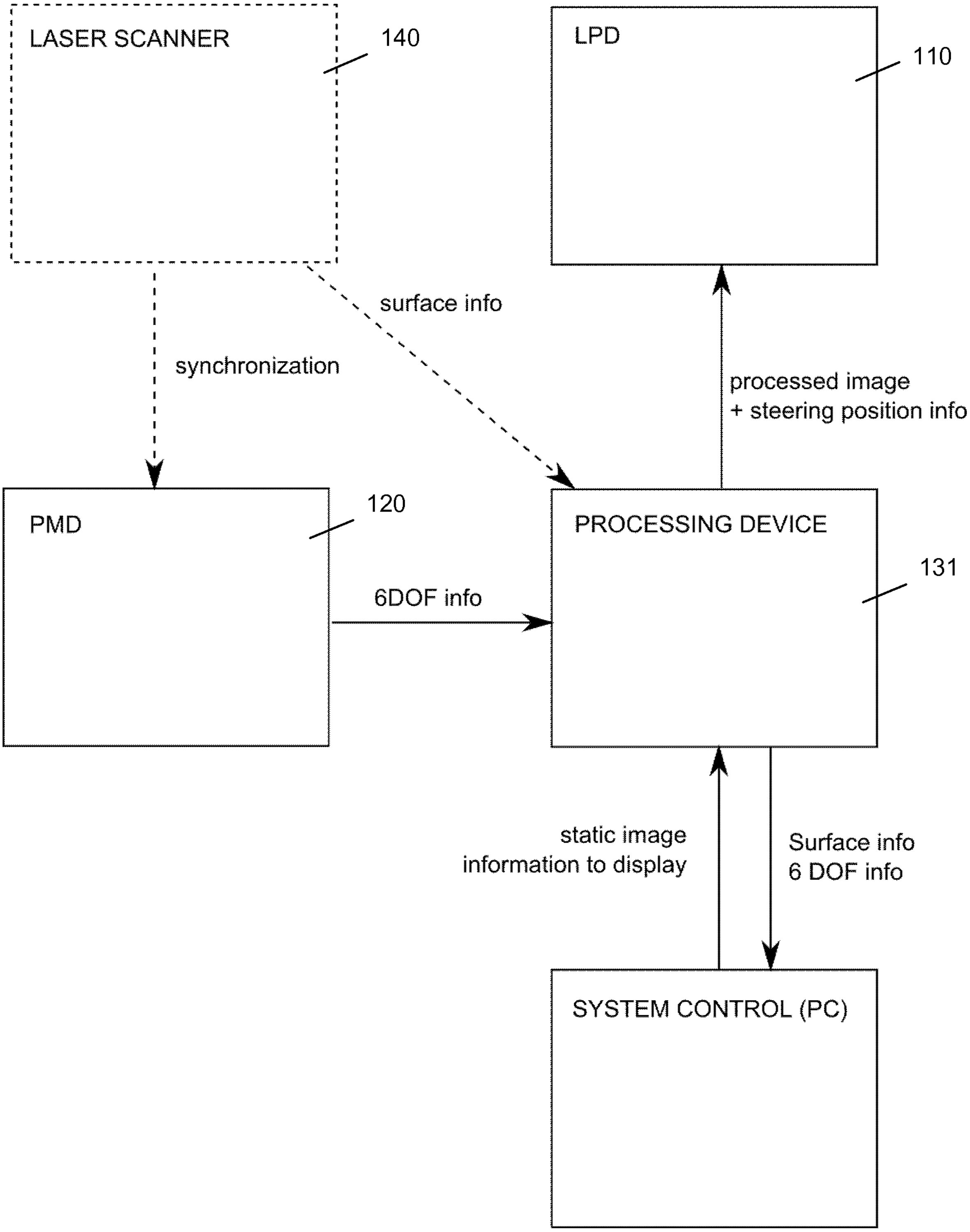
LASER SCANNER
140
LPD
110
surface info
synchronization
processed image
+ steering position info
PMD
120
PROCESSING DEVICE
131
6DOF info
static image
information to display
Surface info
6 DOF info
SYSTEM CONTROL (PC)

FIG. 6

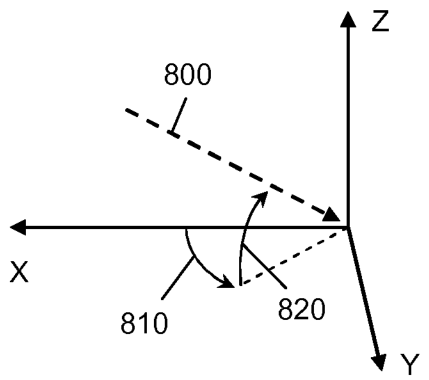

FIG. 7

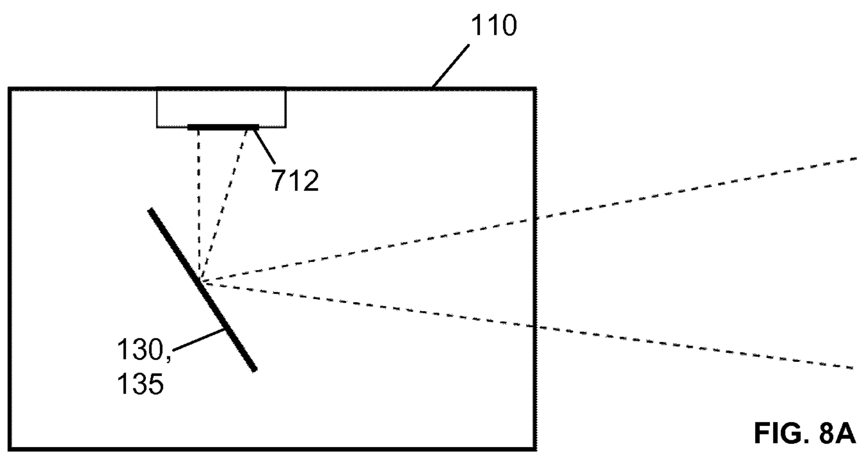

FIG. 8A

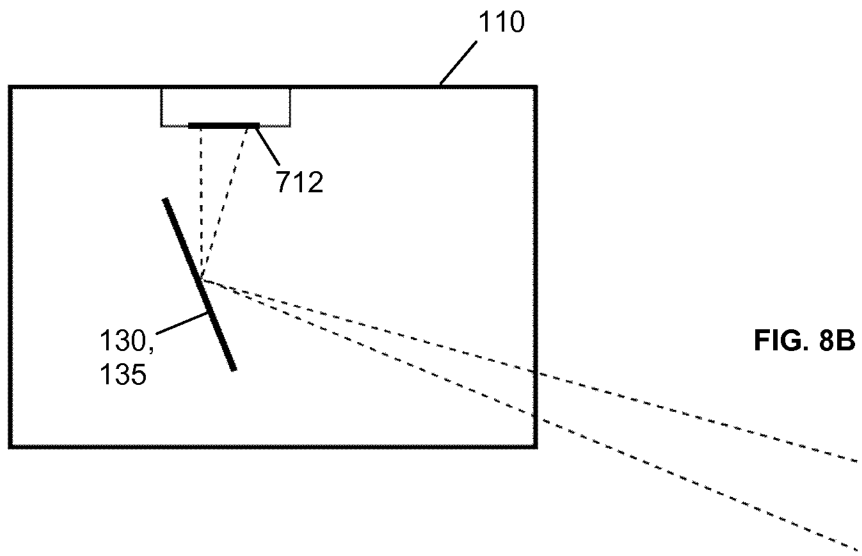

FIG. 8B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/053544

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N9/31 B07C5/34 B07C7/04 G01N21/88 G01N21/95
G01B9/08 G01B21/04 G05B19/402
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)
H04N B25J A61B B07C G01N G01B G05B G03B

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, 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 2011/173827 A1 (BAILEY BRENT [US] ET AL) 21 July 2011 (2011-07-21) paragraph [0030] - paragraph [0032] paragraph [0067] - paragraph [0070] paragraph [0064] paragraph [0060] -----	1-15
X	WO 2011/010313 A1 (OPTIMET OPTICAL METROLOGY LTD [IL]; DANIEL YITZHAK [IL]; WILNER KALMAN) 27 January 2011 (2011-01-27) paragraph [0010] - paragraph [0013] paragraph [0026] - paragraph [0031] paragraph [0042] - paragraph [0044] paragraph [0050] paragraph [0055] - paragraph [0056] ----- -/--	1,2, 4-10,12, 15

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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
19 May 2014	26/05/2014

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

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/053544

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2009/127526 A1 (3D SCANNERS LTD [GB]; VAN COPPENOLLE BART [BE]) 22 October 2009 (2009-10-22) page 1, line 32 - line 36j page 2, line 28 - line 35 page 4, line 33 - page 6, line 9 -----	1-15
A	US 2009/295712 A1 (RITZAU JAN ROBERT TOBIAS [SE]) 3 December 2009 (2009-12-03) figures 1,2 paragraph [0035] - paragraph [0041] paragraph [0035] - paragraph [0042] paragraph [0048] -----	1-15
A	US 2007/271053 A1 (PALMATEER JOHN W [US]) 22 November 2007 (2007-11-22) paragraph [0018] - paragraph [0026] figure 1 -----	1-15

1

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2014/053544

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