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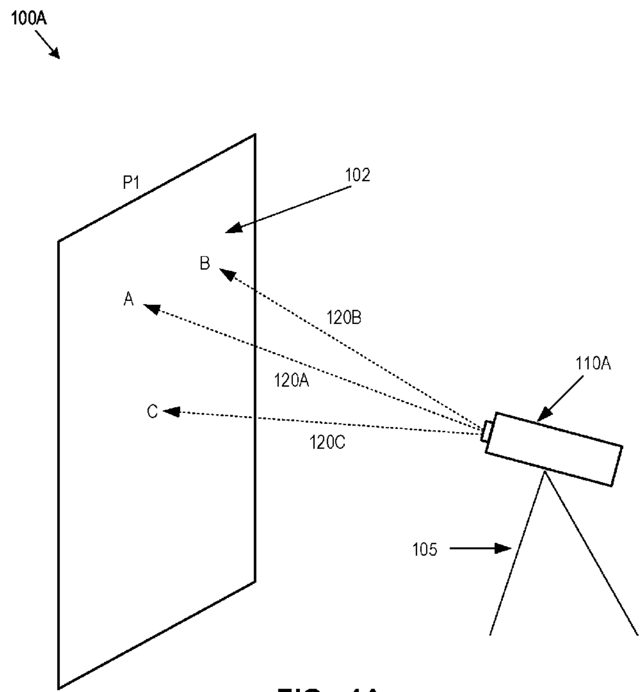

FIG. 1A

(57) **Abstract:** System, method and device for identifying a location of interest. A laser rangefinder is rotatable to a plurality of reference orientations to measure a plurality of reference distances to environmental surface points. The reference distances and reference orientations are used to define a reference plane. A geometrical surface of interest is identified relative to the reference plane. The laser rangefinder is further rotatable to interrogation orientations to measure interrogation distances to interrogation surface points. The spatial coordinates of the interrogation surface point are determined from the interrogation distance and the interrogation orientation and compared to a spatial model of the surface of interest to determine if the interrogation locations are on the surface of interest. Feedback is generated indicating whether the interrogated surface point is a location of interest.

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A LASER-BASED DEVICE FOR MAPPING A COMPUTED GEOMETRY RELATIVE TO A REFERENCE GEOMETRY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of United States Provisional Patent Application No. 62/708,904 filed on December 29, 2017, which is incorporated by reference herein in its entirety.

FIELD

[0002] This disclosure relates generally to environmental mapping, and in particular mapping surface locations within an environment.

INTRODUCTION

[0003] The following is not an admission that anything discussed below is part of the prior art or part of the common general knowledge of a person skilled in the art.

[0004] In many fields, it is important to accurately align objects or new surfaces with existing surfaces. In construction projections, new structures are often built relative to existing structures. For example, walls may need to be parallel to one another, while walls and ceilings may need to be at right angles. In some environments, such as mines or natural environments, rough surfaces and/or debris may interfere with, or preclude, the use of conventional measurement and alignment tools such as tape measures. More generally, conventional measurement and alignment techniques may be time consuming and can be prone to operator error.

SUMMARY

[0005] The following introduction is provided to introduce the reader to the more detailed discussion to follow. The introduction is not intended to limit or define any claimed or as yet unclaimed invention. One or more inventions may reside in any combination or sub-combination of the elements or process steps disclosed in any part of this document including its claims and figures.

[0006] The present applications provide systems, methods and devices usable to align objects and/or surfaces within an environment. In general, embodiments described herein may use a laser to measure distances within the environment. At the same time, the orientation of the laser may be tracked using calibrated on-board instruments. The combination of measurements can be used to geometrically determine relative positions between surfaces and/or objects within the environment. A reference spatial model can be generated based on existing surfaces within the environment. Using the techniques described herein, structures on surfaces near the device can be mapped or laid out through the use of geometric processing and laser distance measurements.

[0007] In accordance with one aspect of this disclosure, which may be used alone or in combination with any other aspect, a device for identifying a location of interest, the device comprising: a base; a laser rangefinder rotatably mounted to the base, the laser rangefinder being rotatable on the base to a plurality of reference measurement orientations, and the laser rangefinder being operable to measure a plurality of reference distances from the laser rangefinder to a plurality of environmental reference surface points, each reference distance corresponding to one of the reference measurement orientations; an orientation sensor operable to detect the orientation of the laser rangefinder; a processor coupled to the laser rangefinder and the orientation sensor, the processor configured to: receive the plurality of reference distances from the laser rangefinder and the corresponding reference measurement orientations from the orientation sensor; define a reference plane using the plurality of reference distances and the corresponding reference measurement orientations; receive user input identifying a geometrical surface of interest relative to the reference plane; define a spatial model of the surface of interest based on the user input; the laser rangefinder is further rotatable on the base to an interrogation orientation, and the laser rangefinder is operable to measure an interrogation distance from the laser rangefinder to an interrogation surface point when positioned in the interrogation orientation; and the processor is further configured to: receive the interrogation distance from the laser rangefinder and the corresponding interrogation orientation from the orientation sensor; determine spatial coordinates of the interrogation surface point using the interrogation distance and the corresponding interrogation orientation; determine that the interrogation surface point is located on the surface of interest by comparing the spatial coordinates of the interrogation surface point and the spatial model of the surface of interest; and output feedback identifying the interrogation surface point as a location of interest.

[0008] In some embodiments, the base may be stationary.

[0009] In some embodiments, the base may be moveable, and the device may further comprise a tracking unit operable to measure at least one of a position of the base and an orientation of the base.

[0010] In some embodiments, the device may further comprise a gravity sensor operable to detect a direction of gravity; the plurality of reference distances may comprise a first reference distance corresponding to a first reference measurement orientation and a second reference distance corresponding to a second reference measurement orientation; and the processor can be configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity.

[0011] In some embodiments, the plurality of reference distances may comprise a first reference distance corresponding to a first reference measurement orientation, a second reference distance corresponding to a second reference measurement orientation, and a third reference distance corresponding to a third reference measurement orientation; and the processor can be configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

[0012] In some embodiments, the laser rangefinder may be operable to measure a plurality of additional interrogation distances from the laser rangefinder to a corresponding plurality of additional interrogation surface locations, each additional interrogation distance having a corresponding additional interrogation orientation; and for each additional interrogation surface location, the processor can be configured to: receive the additional interrogation distance from the laser rangefinder and the corresponding additional interrogation orientation from the orientation sensor; determine spatial coordinates of the additional interrogation surface point using the additional interrogation distance and the corresponding additional interrogation orientation; determine whether the additional interrogation surface point is located on the surface of interest by comparing the spatial coordinates of the additional interrogation surface point and the spatial model of the surface of interest; and output additional feedback identifying whether the additional interrogation surface location is an additional location of interest.

[0013] In accordance with an aspect of this disclosure there is provided a system for identifying a location of interest, the system comprising: a base; a laser rangefinder rotatably mounted to the base, the laser rangefinder being rotatable on the base to a plurality of reference measurement orientations, and the laser rangefinder being operable to measure a plurality of reference distances from the laser rangefinder to a plurality of environmental reference surface points, each reference distance corresponding to one of the reference measurement orientations; an orientation sensor operable to detect the orientation of the laser rangefinder; a processor coupled to the laser rangefinder and the orientation sensor, the processor is configured to: receive the plurality of reference distances from the laser rangefinder and the corresponding reference measurement orientations from the orientation sensor; define a reference plane using the plurality of reference distances and the corresponding reference measurement orientations; receive user input identifying a geometrical surface of interest relative to the reference plane; define a spatial model of the surface of interest based on the user input; the laser rangefinder is further rotatable on the base to an interrogation orientation, and the laser rangefinder is operable to measure an interrogation distance from the laser rangefinder to an interrogation surface point when positioned in the interrogation orientation; and the processor is further configured to: receive the interrogation distance from the laser rangefinder and the corresponding interrogation orientation from the orientation sensor; determine additional spatial coordinates of the interrogation surface point using the interrogation distance and the corresponding interrogation orientation; determine that the interrogation surface point is located on the surface of interest by comparing the additional spatial coordinates of the interrogation surface point and the spatial model of the surface of interest; and output feedback identifying the interrogation surface point as a location of interest.

[0014] In some embodiments, the base may be stationary.

[0015] In some embodiments, the base may be moveable, and the system may further comprise a tracking unit operable to measure at least one of a position of the base and an orientation of the base.

[0016] In some embodiments, the device may comprise a gravity sensor operable to detect a direction of gravity; wherein the plurality of reference distances may comprise a first reference distance corresponding to a first reference measurement orientation and a second reference distance corresponding to a second reference measurement orientation; and the processor can be configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity.

[0017] In some embodiments, the plurality of reference distances may comprise a first reference distance corresponding to a first reference measurement orientation, a second reference distance corresponding to a second reference measurement orientation, and a third reference distance corresponding to a third reference measurement orientation; and the processor can be configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

[0018] In some embodiments, the laser rangefinder may be operable to measure a plurality of additional interrogation distances from the laser rangefinder to a corresponding plurality of additional interrogation surface locations, each additional interrogation distance having a corresponding additional interrogation orientation; and for each additional interrogation surface location, the processor can be configured to: receive the additional interrogation distance from the laser rangefinder and the corresponding additional interrogation orientation from the orientation sensor; determine additional spatial coordinates of the additional interrogation surface point using the additional interrogation distance and the corresponding additional interrogation orientation; determine whether the additional interrogation surface point is located on the surface of interest by comparing the additional spatial coordinates of the additional interrogation surface point and the spatial model of the surface of interest; and output additional feedback identifying whether the additional interrogation surface location is an additional location of interest.

[0019] In some embodiments, the processor may be remote from the base and wirelessly coupled to the laser rangefinder and the orientation sensor.

[0020] In accordance with an aspect of this disclosure, there is provided a method for identifying a location of interest, the method comprising: rotating a laser rangefinder mounted on a base to a plurality of reference measurement orientations relative to the base; measuring a plurality of reference distances from the laser rangefinder to a plurality of environmental reference surface points using the laser rangefinder, each reference distance corresponding to one of the reference measurement orientations; defining a reference plane using the plurality of reference distances and the corresponding reference measurement orientations; receiving user input indicating a geometrical surface of interest relative to the reference plane; defining a spatial model of the surface of interest based on the user input; rotating the laser rangefinder to an interrogation orientation relative to the base; measuring an interrogation distance from the laser rangefinder to an interrogation surface point using the laser rangefinder positioned in the interrogation orientation; determining spatial coordinates of the interrogation surface point using the interrogation distance and the corresponding interrogation orientation; determining that the interrogation surface point is located on the surface of interest by comparing the spatial coordinates of the interrogation surface point and the spatial model of the surface of interest; and outputting feedback identifying the interrogation surface point as a location of interest.

[0021] In some embodiments, the method may comprise detecting a direction of gravity; the plurality of reference distances may comprise a first reference distance corresponding to a first reference measurement orientation and a second reference distance corresponding to a second reference measurement orientation; and the reference plane can be defined using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity

[0022] In some embodiments, the plurality of reference distances may comprise a first reference distance corresponding to a first reference measurement orientation, a second reference distance corresponding to a second reference measurement orientation, and a third reference distance corresponding to a third reference measurement orientation; and the reference plane can be defined using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

[0023] In some embodiments, the method may further comprise marking the interrogation surface point as the location of interest.

[0024] In some embodiments, the method may further comprise: measuring a plurality of additional interrogation distances from the laser rangefinder to a corresponding plurality of additional interrogation surface locations, each additional interrogation distance having a corresponding additional interrogation orientation of the laser rangefinder relative to the base; determining additional spatial coordinates of the additional interrogation surface point using the additional interrogation distance and the corresponding additional interrogation orientation; determining whether the additional interrogation surface point is located on the surface of interest by comparing the additional spatial coordinates of the additional interrogation surface point and the spatial model of the surface of interest; and outputting additional feedback identifying whether the additional interrogation surface location is an additional location of interest.

[0025] In some embodiments, the method may further comprise: positioning an object within an environment in which the laser rangefinder is located; and the interrogation surface point may be on a surface of the object.

[0026] In some embodiments, the base may be moveable, and the method may further comprise determining at least one of a position and an orientation of the base corresponding to each of the reference measurement orientations and the interrogation orientation.

[0027] It will be appreciated by a person skilled in the art that an apparatus or method disclosed herein may embody any one or more of the features contained herein and that the features may be used in any particular combination or sub-combination.

[0028] These and other aspects and features of various embodiments will be described in greater detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] For a better understanding of the described embodiments and to show more clearly how they may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:

[0030] FIG. 1A shows a schematic drawing of an example measurement device defining a reference geometry in accordance with an embodiment;

[0031] FIG. 1B shows a schematic drawing of another example measurement device defining a reference geometry in accordance with an embodiment;

[0032] FIG. 2 shows a schematic drawing of an example measurement device identifying a location of interest in accordance with an embodiment;

[0033] FIG. 3 shows a flowchart illustrating an example process for identifying locations of interest in an environment in accordance with an embodiment;

[0034] FIG. 4 shows a flowchart illustrating an example sub-process for scanning potential locations of interest in accordance with an embodiment.

[0035] The drawings included herewith are for illustrating various examples of articles, methods, and apparatuses of the teaching of the present specification and are not intended to limit the scope of what is taught in any way.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[0036] Various apparatuses, methods and compositions are described below to provide an example of an embodiment of each claimed invention. No embodiment described below limits any claimed invention and any claimed invention may cover apparatuses and methods that differ from those described below. The claimed inventions are not limited to apparatuses, methods and compositions having all of the features of any one apparatus, method or composition described below or to features common to multiple or all of the apparatuses, methods or compositions described below. It is possible that an apparatus, method or composition described below is not an embodiment of any claimed invention. Any invention disclosed in an apparatus, method or composition described below that is not claimed in this document may be the subject matter of another protective instrument, for example, a continuing patent application, and the applicant(s), inventor(s) and/or owner(s) do not intend to abandon, disclaim, or dedicate to the public any such invention by its disclosure in this document.

[0037] The terms "an embodiment," "embodiment," "embodiments," "the embodiment," "the embodiments," "one or more embodiments," "some embodiments," and "one embodiment" mean "one or more (but not all) embodiments of the present invention(s)," unless expressly specified otherwise.

[0038] The terms "including," "comprising" and variations thereof mean "including but not limited to," unless expressly specified otherwise. A listing of items does not imply that any or all of the items are mutually exclusive, unless expressly specified otherwise. The terms "a," "an" and "the" mean "one or more," unless expressly specified otherwise.

[0039] As used herein and in the claims, two or more parts are said to be “coupled”, “connected”, “attached”, or “fastened” where the parts are joined or operate together either directly or indirectly (i.e., through one or more intermediate parts), so long as a link occurs. As used herein and in the claims, two or more parts are said to be “directly coupled”, “directly connected”, “directly attached”, or “directly fastened” where the parts are connected in physical contact with each other. None of the terms “coupled”, “connected”, “attached”, and “fastened” distinguish the manner in which two or more parts are joined together.

[0040] Furthermore, it will be appreciated that for simplicity and clarity of illustration, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the example embodiments described herein. However, it will be understood by those of ordinary skill in the art that the example embodiments described herein may be practiced without these specific details. In other instances, well-known methods, procedures, and components have not been described in detail so as not to obscure the example embodiments described herein. Also, the description is not to be considered as limiting the scope of the example embodiments described herein.

[0041] Embodiments described herein generally relate to systems, methods and devices for identifying and mapping a geometric surface of interest within an environment. The surface of interest may be an artificial geometric plane or other artificial geometric shape in the environment. The system can be used to mark locations in the environment corresponding to the artificial surface of interest, and to align objects and/or equipment to that artificial surface of interest.

[0042] In embodiments described herein, a system or device may be configured to map an artificial geometric surface (e.g. a computed geometrical plane) relative to a reference plane in a given environment. The system or device may be referred herein generally to as a geometric mapping apparatus.

[0043] The relationship between the geometric mapping apparatus and the reference plane, and the relationship between the reference plane and the artificial geometric surface, can be used to define a spatial model of the artificial geometric surface relative to the geometric mapping apparatus (e.g. a plane equation of an artificial geometric plane). The apparatus may then identify locations within the environment whose spatial coordinates correspond to the spatial model of the artificial surface.

[0044] The apparatuses described herein can include a laser rangefinder. The position of the laser rangefinder in the environment may provide an initial reference point in the three-dimensional space of the environment. The laser rangefinder can measure the distance to a given surface location within the environment.

[0045] The laser rangefinder can be rotatably mounted to a base. That is, the laser rangefinder may be mounted to the base with a pivotable or rotatable mounting that allows the laser rangefinder to be rotated (e.g. swiveled) and/or tilted.

[0046] The orientation of the laser rangefinder relative to the base can be monitored. The orientation of the laser rangefinder can be stored for each distance measurement. Accordingly, the spatial coordinates of surface locations in the environment relative to the laser rangefinder can be determined using the measured distance and the corresponding laser rangefinder orientation.

[0047] By identifying the spatial coordinates of multiple surface locations in the environment, a reference plane can be identified. For example, the reference plane may be defined by the surface of a wall or a floor or a ceiling or an object within the environment. In some cases, the reference plane can be defined by surfaces of multiples walls and/or floors and/or ceilings and/or objects within the environment.

[0048] In some cases, the reference plane may be defined using the spatial coordinates of three (3) surface locations within the environment. The laser rangefinder can be used to determine the spatial coordinates of each surface location relative to the rangefinder. The plane defined by the three (3) surface locations can then be determined geometrically. This reference plane may be defined as a three-dimensional spatial model relative to the geometric mapping apparatus. As a skilled reader will appreciate, the three (3) surface locations defining a plane cannot be collinear.

[0049] In some cases, the reference plane may be defined using the spatial coordinates of only two (2) surface locations within the environment. The apparatus may also include a gravity sensor usable to determine a gravity vector (i.e. the direction of gravity). This may enable the identification of a vertical reference plane using the spatial coordinates of only two reference surface locations. The geometric mapping apparatus may then geometrically determine the reference plane as the plane defined by the two (2) surface locations and the gravity vector.

[0050] The reference surface locations may be identified by a user operating the geometric mapping apparatus. For example, a user may target reference surface locations by adjusting the orientation of the laser rangefinder. In some cases, the user may manually adjust the orientation of the laser rangefinder. In other cases, the user may input reference measurement orientations and the laser rangefinder can be automatically rotated to those measurement orientations when taking a distance measurement.

[0051] In some cases, the apparatus may also include additional orientation sensors. For example, a tracking unit such as an inertial measurement unit or other spatial tracking unit may be included in the apparatus. This may allow the position and/or orientation of the apparatus to be monitored for each measurement, for instance, in cases where the base is moveable.

[0052] In some other cases, the base may remain stationary as the geometric mapping apparatus is used. In some such cases, the tracking unit may be omitted.

[0053] In some cases, a user may input spatial coordinates defining a reference plane relative to the geometric mapping apparatus. In such cases, the geometric mapping apparatus may be usable to identify surface locations corresponding to a surface of interest that is defined relative to the input reference plane.

[0054] The reference plane can be used to define a geometric surface of interest within the environment. The surface of interest may be an artificial geometric surface in that it is not necessarily defined by the surface of an object or structure within the environment. That is, the surface of interest may simply correspond to locations in space within the environment. These locations can include environmental surface points as well as other locations not currently occupied by objects or surfaces in the environment.

[0055] A user may provide a relative geometry input to the geometric mapping apparatus. The relative geometry input may indicate the position, orientation, and shape of the artificial surface of interest relative to the reference plane. In some cases, the relative geometry input may be a rigid transformation of the reference plane that, in turn, defines the surface of interest as a plane of interest. For example, the relative geometry input may identify the plane of interest as a vertical plane parallel to and a specific distance from the reference plane. Other examples may include plane of interests that are translated and/or rotated relative to the reference plane.

[0056] In some cases, other shapes may be identified as the surface of interest. For example, a circular or square surface (or cylinders or cubes etc.) with a user-defined area that is perpendicular to a reference plane with a center point a user-defined distance from the reference plane may be identified. As a simple example, this may allow the corresponding circular or square shape to be identified on the floor of an environment a given distance from a wall in the environment.

[0057] The geometric mapping apparatus may then identify surface locations within the environment that are positioned on the surface of interest. For example, in some cases the geometric mapping apparatus may identify surface locations on the floor (or wall or ceiling) of the environment that intersect the surface of interest. The geometric mapping apparatus may output feedback indicating the surface locations corresponding to the surface of interest (which may be referred to herein as locations of interest). For example, the geometric mapping apparatus may provide a visible and/or audible and/or tactile output indicating that a location of interest has been identified.

[0058] In some cases, the geometric mapping apparatus may also provide feedback as multiple surface locations are interrogated using the laser rangefinder. The feedback may indicate whether or not a surface location being interrogated is a location of interest. For example, the geometric mapping apparatus may output a continual tone or a color of light that changes when a location of interest is identified.

[0059] In some cases, the geometric mapping apparatus may adjust the feedback output gradually based on the absolute distance between a surface location being interrogated and the plane of interest. For example, the color of light may change gradually from red to green as the distance between the surface locations and the surface of interest decreases. Similarly, an audible output may include a periodic sound pulse or tone where the period between subsequent tones decreases gradually as the distance between the surface locations and the surface of interest decreases.

[0060] Using the feedback from the geometric mapping apparatus as a guide, surface locations corresponding to the surface of interest can be identified. For example, a user may mark or otherwise identify locations of interest using a pen or paint or tape for example. The process of identifying and marking locations of interest may be repeated until the surface of interest is suitably identified for the particular application.

[0061] In some cases the geometric mapping apparatus may be used to align an object or objects with the surface of interest in the environment. The geometric mapping apparatus may interrogate surface locations on the object within the environment. As explained above, the geometric mapping apparatus can provide feedback indicating whether the interrogated surface locations are positioned on the surface of interest. In some cases, the geometric mapping apparatus may provide feedback indicative of the distance from the surface locations to the surface of interest. The object may then be moved within the environment as the surface locations are being interrogated, for example until the surface locations are positioned on the surface of interest.

[0062] Referring now to FIG. 1A, shown therein is an example of a geometric mapping system 100A in accordance with an embodiment. The geometric mapping system 100A may be used to identify a location of interest in the environment surrounding the geometric mapping system 100A. In the example shown in FIG. 1A, the geometric mapping system 100A is used to define a reference plane P1.

[0063] In general, the geometric mapping system 100A may be used to identify a computed/artificial geometrical surface within the environment. The artificial geometrical surface can be mapped from a reference geometrical surface that is determined based on environmental surface locations around the geometric mapping system 100A. A portion of the geometrical mapping system 100A can define a system reference point in the three-dimensional space of the system environment. The reference geometrical surface can then be defined using spatial coordinates relative to the system reference point. The geometric mapping system 100A may then map the intersections of the computed geometry of interest and surfaces in the environment as locations of interest.

[0064] The geometric mapping system 100A includes a laser rangefinder unit 110A. As shown in the example of FIG. 1A, the laser rangefinder 110A can be mounted to a base 105.

[0065] In general, the laser rangefinder 110A is a device that uses a laser beam to determine the distance to an object or surface. For example, the laser rangefinder 110A may use a time of flight principle to determine the distance to an object being interrogated. A laser pulse may be emitted in a narrow beam towards the object or surface. By measuring the time taken by the pulse to reflect off the target object/surface and return to the laser rangefinder 110A, the distance to the target can be determined. The position of the laser rangefinder 110A may define a spatial reference location within the environment (e.g. a spatial origin).

[0066] The laser rangefinder 110A can be rotatably mounted to a base 105 to allow the orientation of the laser rangefinder 110A (relative to the base) to be adjusted). A rotatable or pivotable mount may allow the laser rangefinder 110A to swiveled and/or tilted relative to the base 105.

[0067] The geometric mapping system 100A may include an orientation sensor that is usable to monitor the orientation of the laser rangefinder 110A relative to the base 105. For example, a simple mechanical orientation sensor may monitor the change in orientation of the laser rangefinder 110A as it is rotated. In other cases, the orientation sensor may monitor the orientation of the laser rangefinder 110A electronically. In some cases, the orientation sensor may even include position and/or orientation tracking units for the laser rangefinder 110A and base 105, such as inertial measurement sensors operable to determine an absolute orientation of the rangefinder 110A. The tracking units may be incorporated into the laser rangefinder 110A and/or based 105.

[0068] The laser rangefinder 110A can be used to identify the spatial location of a plurality of reference surface locations within an environment. The plurality of reference surface locations can then be used to identify a reference plane in the environment.

[0069] In the example shown in FIG. 1A, the laser rangefinder 110A is operated to identify the spatial coordinates of three (3) surface locations A, B, and C on a wall 102. Each of the surface locations A, B, C correspond to spatial locations on a plane P1 defined by the surface of the wall 102.

[0070] The laser rangefinder 110A can be rotated relative to the base 105 to a plurality of reference measurement orientations. The reference measurement orientations can be selected in order to interrogate reference surface locations A, B, C on a reference surface such as wall 102.

[0071] In some cases, a user may manually adjust the orientation of laser rangefinder 110A to target the reference surface locations A, B, C. In some cases, the orientation may be adjusted using a remote control system (not shown) that is coupled to the laser rangefinder 110A using a wired or wireless connection.

[0072] As shown in FIG. 1A, the laser rangefinder 110A may be rotated to three reference measurement orientations. Each reference measurement orientation may correspond to one of the environmental surface locations A, B, C. The laser rangefinder 110A can be used to measure the distance from the laser rangefinder 110A to each environmental surface locations A, B, C (referred to as a reference distance or reference point distance). Each of the reference distances may correspond to a particular reference measurement orientation.

[0073] The laser rangefinder 110A can be adjusted to a first measurement orientation targeting the surface location A. The laser rangefinder 110A can transmit a laser pulse 120A to the surface location A, and measure the time required for the pulse 120A to reflect off the surface location A and return. Similarly, the laser rangefinder 110A can transmit laser pulses 120B and 120C to the environmental surface locations B and C respectively when positioned in second and third measurement orientations.

[0074] Using the reference distance from the laser rangefinder 110A to a given environmental surface location, and the corresponding measurement orientation, the spatial coordinates of the given environmental surface location can be determined relative to the laser rangefinder 110A (e.g. using the laser rangefinder 110A as the origin in a Cartesian coordinate system).

[0075] The geometric mapping system 100A can also include a processor (not shown). The processor may be any suitable processor, controller or digital signal processor that can provide sufficient processing power depending on the configuration, purposes and requirements of the geometric mapping system 100A as is known by those skilled in the art. Similarly, the geometric mapping system

100A may include volatile and non-volatile memory required for the processes performed by the geometric mapping system 100A.

[0076] For example, the processor may be a high performance general processor. In some embodiments, the processor may include more than one processor with each processor being configured to perform different dedicated tasks. In some embodiments, the processor may be provided using specialized hardware such as an FPGA or application specific circuitry. In some embodiments, the processor may be provided by a desktop computer, a laptop computer, a tablet, a handheld device such as a smartphone and the like.

[0077] In some cases, the processor may be included with the laser rangefinder 110A. Alternatively, the processor may be located remote from the laser rangefinder unit 110A and may be coupled thereto using either a wired or wireless connection.

[0078] In general, the processor can be coupled to the laser rangefinder 110A and the orientation sensor. The processor can receive the plurality of reference distances from the laser rangefinder 110A. The processor can also receive the corresponding reference measurement orientations from the orientation sensor. Using the plurality of reference distances and the corresponding reference measurement orientations, the processor can define a reference plane. The reference plane can be defined as a spatial model relative to the laser rangefinder 110A.

[0079] For example, the positions of the environmental surface locations A, B and C can be determined as $A = (x_A, y_A, z_A)$, $B = (x_B, y_B, z_B)$, and $C = (x_C, y_C, z_C)$ using the plurality of reference distances and the corresponding reference measurement orientations. The reference plane may then defined by the set of coordinates x, y, and z that satisfy the equation

$$\begin{vmatrix} x - x_A & y - y_A & z - z_A \\ x_B - x_A & y_B - y_A & z_B - z_A \\ x_C - x_A & y_C - y_A & z_C - z_A \end{vmatrix} = 0$$

where $|M|$ denotes the determinant of the matrix M.

[0080] In some examples, as shown in FIG. 1A, the plurality of reference distances may include at least three (3) reference distances, each corresponding to a different environmental surface location. Each reference distance has a corresponding reference measurement orientation of the laser rangefinder 110A. The reference plane may then be defined using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

[0081] In some cases, the three (3) environmental surface locations used to define the reference plane need not be on the same surface. For example, the environmental surface locations may include surface locations on a wall and the ceiling or floor, and the corresponding reference plane can be defined extending between those environmental surface locations. However, as a skilled reader will appreciate, in order to define the reference plane, the three (3) environmental surface locations cannot all be collinear. In some other examples, as shown in FIG. 1B described herein below, only two reference distances may be required.

[0082] In the example shown in FIG. 1A, the processor can use the reference distances to environmental surfaces locations A, B and C, as well as the corresponding measurement orientations to identify the plane P1 defined by wall 102. The processor can define the reference plane (i.e. P1) to include a set of spatial coordinates that are defined in relation to the position of the laser rangefinder 110A. The reference plane may be used as the basis for identifying surface locations of interest within the environment, as described in further detail herein below with reference to FIGS. 2, 3 and 4.

[0083] The base 105 may be provided in various forms. For example, a tripod or other similar structure may be used as the base 105.

[0084] In some cases, the base 105 may be stationary. That is, the base 105 may remain in the same position and orientation while the laser rangefinder 110A is adjusted. This may simplify the procedure of identifying a reference plane and detecting locations of interest, since the only changes to the position/orientation of the laser rangefinder 110A may be from rotating the rangefinder 110A relative to the base 105. For example, the orientation can be as simple as a read-out of degrees on a mechanical scale. In some such embodiments, onboard IMU (Inertial Measurement Unit) components may be omitted.

[0085] In some cases, the base 105 may be moveable. For example, the base 105 may include wheels to allow the base 105 to be easily moved within an environment. In such cases, the base 105 may include a tracking unit that is operable to measure a position and/or orientation of the base 105. For example, the base 105 may be mounted to a track. The tracking unit may then mechanically determine the position of the base 105 along the track. Alternatively, the tracking unit may include an inertial measurement unit. The inertial measurement unit may include position and orientation sensors useable to measure a position and orientation of the base 105. The position and orientation of the laser rangefinder 110A may then be determined based on the position/orientation of the base 105 and the orientation of the laser rangefinder 110A relative to the base 105.

[0086] An example of a device that may be usable with a moveable base 105 is described in US Patent No. 8,717,579 entitled “Distance measuring device using a method of spanning separately targeted endpoints”, the entirety of which is incorporated herein by reference. Such devices may implement simultaneous localization and mapping (SLAM) techniques to determine the reference planes. For example, in embodiments where the base 105 is moveable, the position and orientation of the base 105 corresponding to each of the distance measurements performed by the laser rangefinder 110 (such as the reference distance measurements and interrogation distance measurements) may also be determined using an IMU.

[0087] Additionally or alternatively, the laser rangefinder 110A may include an inertial measurement unit. The IMU may be useable to monitor absolute changes in the orientation of the laser rangefinder 110A.

[0088] In some cases, all the components (i.e. the laser rangefinder 110A, base 105, orientation sensor, processor, outputs, inputs and any additional sensors) of the geometric mapping system 100A may be enclosed within a single geometric mapping device. Alternatively, the components may be provided by a plurality of devices that are coupled to provide the functionality of the geometric mapping apparatus 100A. For example, the processor and/or output components may be separate from the laser rangefinder 110A, orientation sensor and base 105 and coupled thereto by wired or wireless connections.

[0089] In some cases, geometric mapping apparatus 100A may also be configured to define the location of the environmental surface locations, reference planes etc. using exact Earth-space coordinates. For example, the geometric mapping apparatus 100A may include geo-location components, such as a GPS unit. In some cases, a user may input the location of the geometric mapping apparatus 100A, e.g. as a set of latitude and longitude coordinates. The precise location of the laser rangefinder 110A in Earth-space coordinates may then be determined using the GPS unit or input data. The Earth-space coordinates of the environmental surface locations, reference planes, and surface locations of interest can then be determined based on their locations relative to the laser rangefinder 110A.

[0090] The geometric mapping apparatus 110A can also include one or more output components, such as one or more speakers, lights, displays, tactile feedback components and the like. In some cases, the geometric mapping apparatus 110A may have a corresponding software application installed on a user device, such as a smartphone or tablet, that can be used to provide the feedback. The output components can be used to output feedback to a user of the geometric mapping apparatus 110A.

[0091] Referring now to FIG. 1B, shown therein is another example of a geometric mapping system 100B. The geometric mapping system 100B is generally similar to the mapping system 100A shown in FIG. 1A, with the notable addition of a gravity sensor 114 in system 100B. The gravity sensor 114 is operable to detect the direction of gravity (i.e. a gravity vector $\vec{G}$) in the environment.

[0092] The system 100B allows a reference plane P1' to be determined using the spatial coordinates of only two (2) environmental surface locations A and B. The laser rangefinder 110B can measure a first reference distance to surface location A while positioned in a first reference measurement orientation. The laser rangefinder 110B can also measure a second reference distance to surface location B when positioned in a second reference measurement orientation.

[0093] The processor may then determine the reference plane geometrically using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity $\vec{G}$ determined by the gravity sensor 114. The system 100B can determine the location of the environmental surface locations A and B as $A = (x_A, y_A, z_A)$, $B = (x_B, y_B, z_B)$, and the gravity vector $\vec{G} = (g_X, g_Y, g_Z)$, where $\vec{G}$ is a vector pointing in the direction of gravity. The reference plane can then defined by the set of coordinates x, y, and z that satisfy the equation

$$\begin{vmatrix} x - x_A & y - y_A & z - z_A \\ x_B - x_A & y_B - y_A & z_B - z_A \\ g_X & g_Y & g_Z \end{vmatrix} = 0$$

where $|M|$ denotes the determinant of the matrix M.

[0094] As shown in FIG. 1B, the plane P1' can be determined as a vertical plane that includes the surface locations A and B. This may simplify the process of determining vertical reference planes, for instance when the reference surface location is a vertical wall. However, the reference plane may not be so limited, as the physical surface or surfaces on which A and B are located need not be planar.

[0095] Once a reference plane (e.g. P1 or P1') has been determined, a user may identify a requested artificial geometric surface. The requested artificial plane may be defined geometrically relative to the reference plane. For example, the computed geometry may be identified as an artificial plane using a rigid transformation of the reference plane such as a translation and/or a rotation. The processor may then determine the artificial plane corresponding to the computed geometry as the surface of interest.

[0096] In the example shown in FIG. 2, the artificial surface of interest P2 was defined as a plane parallel to the reference plane P1 that has been translated by a user-specified distance. The processor may then generate a spatial model of the plane of interest P2 from which spatial coordinates corresponding to the plane of interest P2 can be identified.

[0097] For example, given the parametric form of P1 (shown above) $ax + by + cz + d = 0$ and an offset distance of s towards the laser rangefinder 110, a plane of interest P2 can be defined by the set of coordinates x, y, and z that satisfy the equation

$$ax + by + cz + s\sqrt{a^2 + b^2 + c^2} - d = 0.$$

[0098] The geometric mapping system 150 may then be used to identify surface locations that correspond to (i.e. are positioned on) the plane of interest P2.

[0099] As mentioned, the surface of interest is not limited to a plane of interest but more generally can be an artificial geometric surface. For example, given a vertical reference plane (parallel to z) in the form $ax + by + d = 0$, a vertical cylinder of interest (such as a column or a pipe) can be defined with a radius r and center coordinate $C = (x_C, y_C)$ as the set of coordinates x, y, and z that satisfy $(x - x_C)^2 + (y - y_C)^2 = r^2$.

[00100] The distance from the center coordinate to the reference plane can also be determined as $\frac{ax_C + by_C + d}{\sqrt{a^2+b^2}}$. As a skilled reader will appreciate, this spatial model can be expanded to cylinders in arbitrary directions and located at arbitrary positions relative to the reference plane. Similar spatial models can be used for other shapes, such as cubes for example.

[00101] In some cases, multiple reference planes may be identified using the geometric mapping apparatuses 100A and/or 100B. This may allow additional surfaces of interest to be identified, such as a surface of interest that is in the middle of two walls or that corresponds to the intersection of the reference planes.

[00102] In the example geometric mapping system 150 shown in FIG. 2, the laser rangefinder unit 110 is used to identify surface locations of interest corresponding to the artificial plane of interest P2. In general, the geometric mapping system 150 shown in FIG. 2 may be implemented in a manner analogous to geometric mapping systems 100A and 110B.

[00103] The laser rangefinder 110 can be used to interrogate one or more surface locations within the environment. Using the position of the laser rangefinder 110 as a spatial reference point, the spatial coordinates of the surface locations can be determined based on the distance from the laser rangefinder 110 to the surface location point and the orientation of the laser rangefinder. The spatial locations of the interrogated surface locations can then be compared to the spatial model of the surface of interest to determine if those interrogated surface locations are locations of interest that intersect the surface of interest (i.e. are located on the plane of interest P2).

[00104] As shown in FIG. 2, the laser rangefinder 110 may scan along a surface in the environment to identify the surface locations on the plane of interest. The laser rangefinder 110 may be oriented to target the floor 130 of the

environment. By adjusting the orientation of the laser rangefinder 110, the surface location on the floor 130 being interrogated can be changed. The orientation of the laser rangefinder 110 may be adjusted gradually until a surface location of interest *D* is identified on the plane of interest *P2*. The geometric mapping apparatus 150 may then output feedback, such as visual or audio signal, identifying the location as a location of interest. This process may be repeated until a desired number of surface locations of interest are identified.

[00105] In some cases, the geometric mapping apparatus 150 may be configured to emit a scanning laser line to identify surface locations of interest. The geometric mapping apparatus 150 may include additional components as necessary to implement such a scanning configuration.

[00106] As shown in FIG. 2, the geometric mapping apparatus has scanned the floor 130 to identify a surface location point D that intersects the physical floor 130 of the environment and the artificial surface of interest P2. The coordinates of D can be determined by the orientation of the laser rangefinder 110 and the measured distance from the laser rangefinder to D. When these coordinates satisfy the P2 spatial model (i.e. the plane equation of P2), the point D lies on the plane P2.

[00107] When the surface location of interest D is identified, the user can be notified of the intersection. A user may then the location of interest at the surface location point illuminated by the laser from laser rangefinder 110. The marking process can continue until the surface of interest is sufficiently mapped. For example, the marking process can continue until the computed geometry is sufficiently mapped, or laid out on physical surfaces in the environment. The marked locations may subsequently be used to construct a structure, such as a wall, or to align equipment. For example, a user may mark a line on the floor 130 that intersects plane P2 so that equipment or a new structure can be subsequently aligned with the plane P2.

[00108] Alternatively, the laser rangefinder 110 may be used directly to align an object (e.g. equipment or a new structure) within the environment to the plane of interest. As the object is moved with the environment, the laser rangefinder 110 can be oriented to target a surface location on that object that is to be aligned with the plane of interest. For example, as the object is moved, the orientation of the laser rangefinder 110 can be adjusted so that the same surface location point is targeted. When the surface location point is aligned with the surface of interest, the geometric mapping apparatus may output feedback indicating proper alignment with the surface of interest.

[00109] Referring now to FIG. 3, shown therein is a flowchart of an example process 300 for identifying locations of interest in accordance with an embodiment. Process 300 may be implemented using various geometric mapping systems, such as geometric mapping systems 100A, 100B and 150 described herein above.

[00110] At 310, a plurality of reference environmental surface locations can be identified. The reference environmental surface locations may be identified by a user of the geometric mapping system. For example, the reference surface locations may be chosen on a wall within the environment. This may be particularly useful when the purpose is to align a new surface or an object with that wall. As a skilled reader will appreciate, the particular reference surface locations chosen may vary depending on the purpose of the geometric mapping being performed.

[00111] Furthermore, as explained above, the number of reference surface locations may vary depending on the particular application and/or device being used. For example, where the reference plane is to be a vertical plane and the geometric mapping system includes a gravity sensor, only two reference surface locations may be required. In other cases, at least three reference surface locations may be required.

[00112] At 320, the laser rangefinder 110 can be rotated to a plurality of reference measurement orientations. The laser rangefinder 110 may then be used

to measure a plurality of reference distances to the environmental surface location points identified at 310. Each of the reference distances measured may correspond to one of the reference measurement orientations.

[00113] At 330, a reference plane can be defined using the plurality of reference distances and the corresponding reference measurement orientations. For example, where three (3) environmental surface locations were interrogated at 320 (and the surface locations are not collinear), the reference plane can be defined as the geometric plane including all three (3) environmental surface locations.

[00114] In other cases, the geometric mapping system may identify a gravity vector (defining the direction of gravity) using onboard sensors measure reference distances to two (2) environmental surface locations. The geometric mapping system may define the reference plane as the plane defined by the two surfaces points (i.e. the spatial coordinates of the surface points determined using the reference distances and corresponding measurement orientations) and the gravity vector.

[00115] At 340, the geometric mapping apparatus can receive user input defining a geometric surface of interest relative to the reference plane. The geometric mapping apparatus may then define a spatial model of the geometric surface of interest based on the user input and the spatial model of the reference plane.

[00116] For example, the user input may define a rigid transformation of the reference plane. The geometric mapping apparatus may then define the surface of interest as the geometric plane corresponding to the user-defined rigid transformation of the reference plane. For example, as described above with reference to FIG. 2, the plane of interest may be defined as a plane parallel to the reference plane but translated by a defined distance. Alternatively, other geometric surfaces of interest can be defined, such as cylinders or cubes for example.

[00117] At 350, the geometric mapping apparatus can be used to identify locations of interest in the environment. The locations of interest can be identified as locations that correspond to the surface of interest.

[00118] The laser rangefinder 110 can be rotated to an interrogation orientation relative to base 105. The interrogation orientation can be selected so that laser rangefinder 110 targets/interrogates a particular potential surface location of interest in the environment.

[00119] The laser rangefinder 110 can then measure an interrogation distance from the laser rangefinder 110 to an interrogation surface point. The interrogation orientation corresponds to the orientation of the laser rangefinder 110 when the laser beam is emitted towards an interrogation surface point (i.e. a potential surface location of interest). The interrogation distance and interrogation orientation can be used to determine the spatial coordinates of the interrogation surface point.

[00120] The processor may then determine whether the interrogation surface location is located on the surface of interest. If the spatial coordinates of the interrogation surface location satisfy the spatial model of the surface of interest (e.g. the plane equation of a plane of interest), then the interrogation surface point can be identified as a location of interest on the surface of interest. In some cases, the interrogation surface locations can be identified as locations of interest as long as they are within a given threshold distance of the surface of interest. The threshold distance may be a user-defined tolerance distance.

[00121] The geometric mapping apparatus may then output feedback identifying the interrogation surface point as a location of interest. For example, the geometric mapping apparatus may provide feedback in the form of an audio tone or a visual signal. Various other forms of feedback, such as an output display may also be used. This can signal to a user that a location of interest has been identified.

[00122] In some cases, the interrogation surface point may then be marked as a location of interest. For example, a user may mark or otherwise identify locations of interest using a pen or paint or tape for example. This may subsequently allow objects or structures to be aligned with the surface of interest.

[00123] In some cases, the geometric mapping apparatus can be used to directly align objects or structures in the environment. For example, an object can be positioned within the line of sight of the laser rangefinder 110. The laser rangefinder 110 can be oriented so that the interrogation surface point is on the surface of the object. The object may then be moved within the environment as the laser rangefinder measures a reference distance thereto. When the surface of the object is identified as a location of interest, this may indicate that the object is properly aligned (assuming, of course, that an appropriate surface point on the object is being targeted).

[00124] In some cases, the geometric mapping apparatus may adjust the feedback output gradually depending on the absolute distance between a surface location being interrogated and the surface of interest. For example, the color of light may change gradually from red to green as the distance between the surface locations and the surface of interest decreases. Similarly, an audible output may include a periodic sound pulse or tone where the period between subsequent tones decreases gradually as the distance between the surface locations and the surface of interest decreases. This may further facilitate the process of aligning an object with the surface of interest.

[00125] Referring now to FIG. 4, shown therein is a flowchart of an example sub-process 400 for identifying a location of interest in accordance with an embodiment. Sub-process 400 may be used in embodiments of the process 300 described above. Sub-process 400 may be implemented using various geometric mapping systems, such as geometric mapping systems 100A, 100B and 150 described herein above.

[00126] At 410, a surface of interest can be defined in the environment. The surface of interest can be defined as described herein above, for example at step 350 of process 300. The geometric mapping apparatus may then scan interrogation surface locations within the environment to identify locations corresponding to the surface of interest.

[00127] At 420, the laser rangefinder 110 can be used to measure an interrogation distance from the laser rangefinder 110 to an interrogation surface point when positioned in an interrogation orientation. As mentioned above, the interrogation surface point may be located on an environmental surface or on the surface of an object positioned in the environment.

[00128] At 430, the geometric mapping apparatus may determine whether the interrogation surface point is located on the surface of interest using the interrogation distance and the corresponding interrogation orientation. If the spatial coordinates of the interrogation surface point correspond to the spatial model of the surface of interest, then the interrogation surface point can be identified as a location of interest and the method can proceed to step 460. However, if the spatial coordinates of the interrogation surface point do not correspond to the spatial model of the surface of interest (i.e. the interrogation surface point is not on the surface of interest), the method may optionally proceed to step 440, or may proceed directly to step 450.

[00129] At 440, the geometric mapping apparatus may provide a feedback output indicating that the interrogation surface point is not a location of interest. In some cases, the feedback output may provide an indication of the relative distance to the plane of interest (e.g. by varying the color of an output light).

[00130] At 450, the interrogation surface location may be adjusted. The process 400 may then return to step 420 where the laser rangefinder 110 can measure an additional interrogation distance to the new interrogation surface location.

[00131] The laser rangefinder 110 may measure a plurality of additional interrogation distances from the laser rangefinder 110 to a corresponding plurality of additional interrogation surface locations. Each additional interrogation distance can have a corresponding additional interrogation orientation.

[00132] In some cases, adjusting the interrogation surface location may include adjusting the interrogation orientation of the laser rangefinder 110. This may allow the laser rangefinder 110 to target different locations along a wall or ceiling or floor within the environment. For example, the laser rangefinder 110 may scan along the floor or ceiling to identify points of intersection with a vertical plane, as shown in the example of FIG. 2 described above. Accordingly, the interrogation orientation can be adjusted to scan along the desired surface.

[00133] In some cases, adjusting the interrogation surface location may not require adjust the interrogation orientation. For example, where the geometric mapping apparatus is being used to position an object within the environment (i.e. the interrogation surface locations are on the surface of the object), the object may be moved with or without adjusting the orientation of the laser rangefinder 110. As a result, in some cases, some of the additional interrogation surface locations may have the same additional interrogation orientation. The laser rangefinder 110 may have the same position and orientation, but the object will have been moved, so the measured interrogation distance will change.

[00134] At 460, the geometric mapping apparatus can output feedback indicating that the interrogation surface point is a location of interest. For example, the geometric mapping apparatus may output an audible signal or a particular color of light to indicate that the location being interrogated is on the surface of interest. As explained above, a user may then mark the surface location or determine that an object has been properly aligned within the environment.

[00135] When a location of interest has been identified, the process 400 may again return to step 450 if further locations of interest are required. Steps 420-460

may then be repeated iteratively until all necessary locations of interest are identified.

[00136] In some cases, a user may mark or otherwise identify locations of interest using a pen or paint or tape for example. The process of identifying and marking locations of interest may be repeated until the surface of interest is suitably identified for the particular application.

[00137] The device and process for identifying surface locations of interest described herein may have various practical applications. For example, the geometric mapping apparatuses may be usable to verify the distance between objects within an environment, e.g. to confirm that a pair of walls are a desired distance apart or that a piece of equipment is a desired distance from an environmental surface such as a wall, ceiling or floor.

[00138] The geometric mapping apparatuses may also be usable to verify the orientation of structures within an environment, e.g. by confirming the angles between different surfaces to confirm that structures are parallel or perpendicular (or some other desired angular relation). The height of a wall within the environment may be determined with reference to the level of the floor. Various other geometrical properties may be determined, such as confirming the shapes of objects or structures (e.g. circular, cubical etc.) or outlining shapes in the environment (e.g. circles, squares etc.).

[00139] As used herein, the wording “and/or” is intended to represent an inclusive - or. That is, “X and/or Y” is intended to mean X or Y or both, for example. As a further example, “X, Y, and/or Z” is intended to mean X or Y or Z or any combination thereof.

[00140] While the above description describes features of example embodiments, it will be appreciated that some features and/or functions of the described embodiments are susceptible to modification without departing from the spirit and principles of operation of the described embodiments. For example, the

various characteristics which are described by means of the represented embodiments or examples may be selectively combined with each other. Accordingly, what has been described above is intended to be illustrative of the claimed concept and non-limiting. It will be understood by persons skilled in the art that other variants and modifications may be made without departing from the scope of the invention as defined in the claims appended hereto. The scope of the claims should not be limited by the preferred embodiments and examples, but should be given the broadest interpretation consistent with the description as a whole.

CLAIMS:

1. A device for identifying a location of interest, the device comprising:

a base;

a laser rangefinder rotatably mounted to the base, the laser rangefinder is rotatable on the base to a plurality of reference measurement orientations, and the laser rangefinder is operable to measure a plurality of reference distances from the laser rangefinder to a plurality of environmental reference surface points, each reference distance corresponding to one of the reference measurement orientations;

an orientation sensor operable to detect the orientation of the laser rangefinder;

a processor coupled to the laser rangefinder and the orientation sensor, the processor is configured to:

receive the plurality of reference distances from the laser rangefinder and the corresponding reference measurement orientations from the orientation sensor;

define a reference plane using the plurality of reference distances and the corresponding reference measurement orientations;

receive user input identifying a geometrical surface of interest relative to the reference plane;

define a spatial model of the surface of interest based on the user input;

the laser rangefinder is further rotatable on the base to an interrogation orientation, and the laser rangefinder is operable to measure an interrogation distance from the laser rangefinder to an interrogation surface point when positioned in the interrogation orientation; and

the processor is further configured to:

receive the interrogation distance from the laser rangefinder and the corresponding interrogation orientation from the orientation sensor;

determine spatial coordinates of the interrogation surface point using the interrogation distance and the corresponding interrogation orientation;

determine that the interrogation surface point is located on the surface of interest by comparing the spatial coordinates of the interrogation surface point and the spatial model of the surface of interest; and

output feedback identifying the interrogation surface point as a location of interest.

2. The device of claim 1, wherein the base is stationary.

3. The device of claim 1, wherein the base is moveable, and the device further comprises a tracking unit operable to measure at least one of a position of the base and an orientation of the base.

4. The device of any one of claims 1 to 3, further comprising:

a gravity sensor operable to detect a direction of gravity;

wherein

the plurality of reference distances comprises a first reference distance corresponding to a first reference measurement orientation and a second reference distance corresponding to a second reference measurement orientation; and

the processor is configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity.

5. The device of any one of claims 1 to 3, wherein

the plurality of reference distances comprises a first reference distance corresponding to a first reference measurement orientation, a second reference distance corresponding to a second reference measurement orientation, and a third reference distance corresponding to a third reference measurement orientation; and

the processor is configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

6. The device of any one of claims 1 to 5, wherein

the laser rangefinder is operable to measure a plurality of additional interrogation distances from the laser rangefinder to a corresponding plurality of additional interrogation surface locations, each additional interrogation distance having a corresponding additional interrogation orientation; and

for each additional interrogation surface location, the processor is configured to:

receive the additional interrogation distance from the laser rangefinder and the corresponding additional interrogation orientation from the orientation sensor;

determine spatial coordinates of the additional interrogation surface point using the additional interrogation distance and the corresponding additional interrogation orientation;

determine whether the additional interrogation surface point is located on the surface of interest by comparing the spatial coordinates of the additional interrogation surface point and the spatial model of the surface of interest; and output additional feedback identifying whether the additional interrogation surface location is an additional location of interest.

7. A system for identifying a location of interest, the system comprising:

a base;

a laser rangefinder rotatably mounted to the base, the laser rangefinder is rotatable on the base to a plurality of reference measurement orientations, and the laser rangefinder is operable to measure a plurality of reference distances from the laser rangefinder to a plurality of environmental reference surface points, each reference distance corresponding to one of the reference measurement orientations;

an orientation sensor operable to detect the orientation of the laser rangefinder;

a processor coupled to the laser rangefinder and the orientation sensor, the processor is configured to:

receive the plurality of reference distances from the laser rangefinder and the corresponding reference measurement orientations from the orientation sensor;

define a reference plane using the plurality of reference distances and the corresponding reference measurement orientations;

receive user input identifying a geometrical surface of interest relative to the reference plane;

define a spatial model of the surface of interest based on the user input;

the laser rangefinder is further rotatable on the base to an interrogation orientation, and the laser rangefinder is operable to measure an interrogation distance from the laser rangefinder to an interrogation surface point when positioned in the interrogation orientation; and the processor is further configured to:

receive the interrogation distance from the laser rangefinder and the corresponding interrogation orientation from the orientation sensor;

determine additional spatial coordinates of the interrogation surface point using the interrogation distance and the corresponding interrogation orientation;

determine that the interrogation surface point is located on the surface of interest by comparing the additional spatial coordinates of the interrogation surface point and the spatial model of the surface of interest; and

output feedback identifying the interrogation surface point as a location of interest.

8. The system of claim 7, wherein the base is stationary.

9. The system of claim 7, wherein the base is moveable, and the system further comprises a tracking unit operable to measure at least one of a position of the base and an orientation of the base.

10. The system of any one of claims 7 to 9, further comprising:

a gravity sensor operable to detect a direction of gravity;

wherein

the plurality of reference distances comprises a first reference distance corresponding to a first reference measurement orientation and a second reference distance corresponding to a second reference measurement orientation; and

the processor is configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity.

11. The system of any one of claims 7 to 9, wherein

the plurality of reference distances comprises a first reference distance corresponding to a first reference measurement orientation, a second reference distance corresponding to a second reference measurement orientation, and a third reference distance corresponding to a third reference measurement orientation; and

the processor is configured to define the reference plane using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

12. The system of any one of claims 7 to 11, wherein

the laser rangefinder is operable to measure a plurality of additional interrogation distances from the laser rangefinder to a corresponding plurality of additional interrogation surface locations, each additional interrogation distance having a corresponding additional interrogation orientation; and

for each additional interrogation surface location, the processor is configured to:

receive the additional interrogation distance from the laser rangefinder and the corresponding additional interrogation orientation from the orientation sensor;

determine additional spatial coordinates of the additional interrogation surface point using the additional interrogation distance and the corresponding additional interrogation orientation;

determine whether the additional interrogation surface point is located on the surface of interest by comparing the additional spatial coordinates of the additional interrogation surface point and the spatial model of the surface of interest; and

output additional feedback identifying whether the additional interrogation surface location is an additional location of interest.

13. The system of any one of claims 7 to 12, wherein the processor is remote from the base and is wirelessly coupled to the laser rangefinder and the orientation sensor.

14. A method for identifying a location of interest, the method comprising:

rotating a laser rangefinder mounted on a base to a plurality of reference measurement orientations relative to the base;

measuring a plurality of reference distances from the laser rangefinder to a plurality of environmental reference surface points using the laser rangefinder, each reference distance corresponding to one of the reference measurement orientations;

defining a reference plane using the plurality of reference distances and the corresponding reference measurement orientations;

receiving user input indicating a geometrical surface of interest relative to the reference plane;

defining a spatial model of the surface of interest based on the user input;

rotating the laser rangefinder to an interrogation orientation relative to the base;

measuring an interrogation distance from the laser rangefinder to an interrogation surface point using the laser rangefinder positioned in the interrogation orientation;

determining spatial coordinates of the interrogation surface point using the interrogation distance and the corresponding interrogation orientation;

determining that the interrogation surface point is located on the surface of interest by comparing the spatial coordinates of the interrogation surface point and the spatial model of the surface of interest; and

outputting feedback identifying the interrogation surface point as a location of interest.

15. The method of claim 14, further comprising:

detecting a direction of gravity; and

wherein

the plurality of reference distances comprises a first reference distance corresponding to a first reference measurement orientation and a second reference distance corresponding to a second reference measurement orientation; and

the reference plane is defined using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the direction of gravity

16. The method of claim 14, wherein:

the plurality of reference distances comprises a first reference distance corresponding to a first reference measurement orientation, a second reference distance corresponding to a second reference measurement orientation, and a third reference distance corresponding to a third reference measurement orientation; and

the reference plane is defined using the first reference distance and the first reference measurement orientation, the second reference distance and the second reference measurement orientation, and the third reference distance and the third reference measurement orientation.

17. The method of any one of claims 14 to 16, further comprising marking the interrogation surface point as the location of interest.

18. The method of any one of claims 14 to 17, further comprising:

measuring a plurality of additional interrogation distances from the laser rangefinder to a corresponding plurality of additional interrogation surface locations, each additional interrogation distance having a corresponding additional interrogation orientation of the laser rangefinder relative to the base;

determining additional spatial coordinates of the additional interrogation surface point using the additional interrogation distance and the corresponding additional interrogation orientation;

determining whether the additional interrogation surface point is located on the surface of interest by comparing the additional spatial coordinates of the additional interrogation surface point and the spatial model of the surface of interest; and

outputting additional feedback identifying whether the additional interrogation surface location is an additional location of interest.

19. The method of any one of claims 14 to 18, further comprising:

positioning an object within an environment in which the laser rangefinder is located; and

wherein the interrogation surface point is on a surface of the object.

20. The method of any one of claims 14 to 19, wherein the base is moveable, and the method further comprises determining at least one of a position and an orientation of the base corresponding to each of the reference measurement orientations and the interrogation orientation.

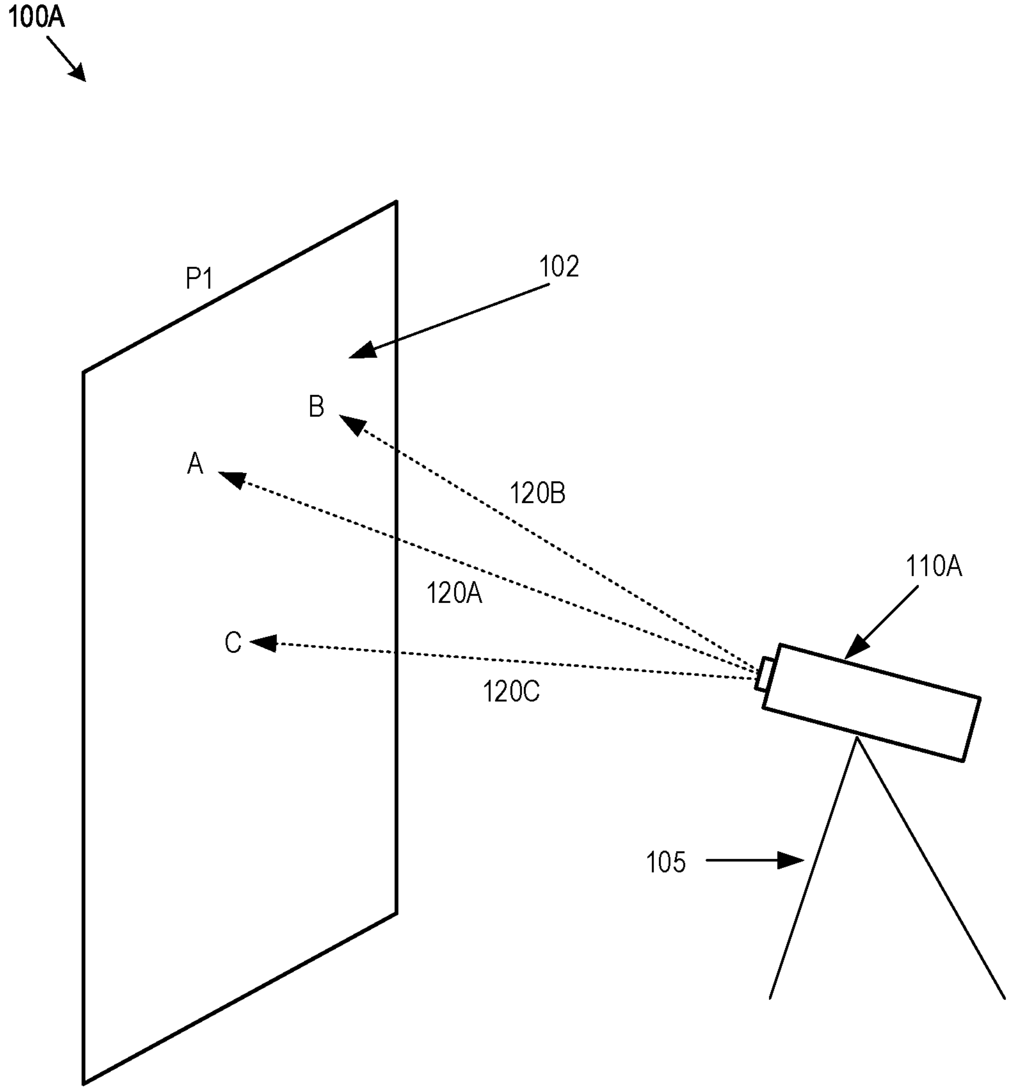

FIG. 1A

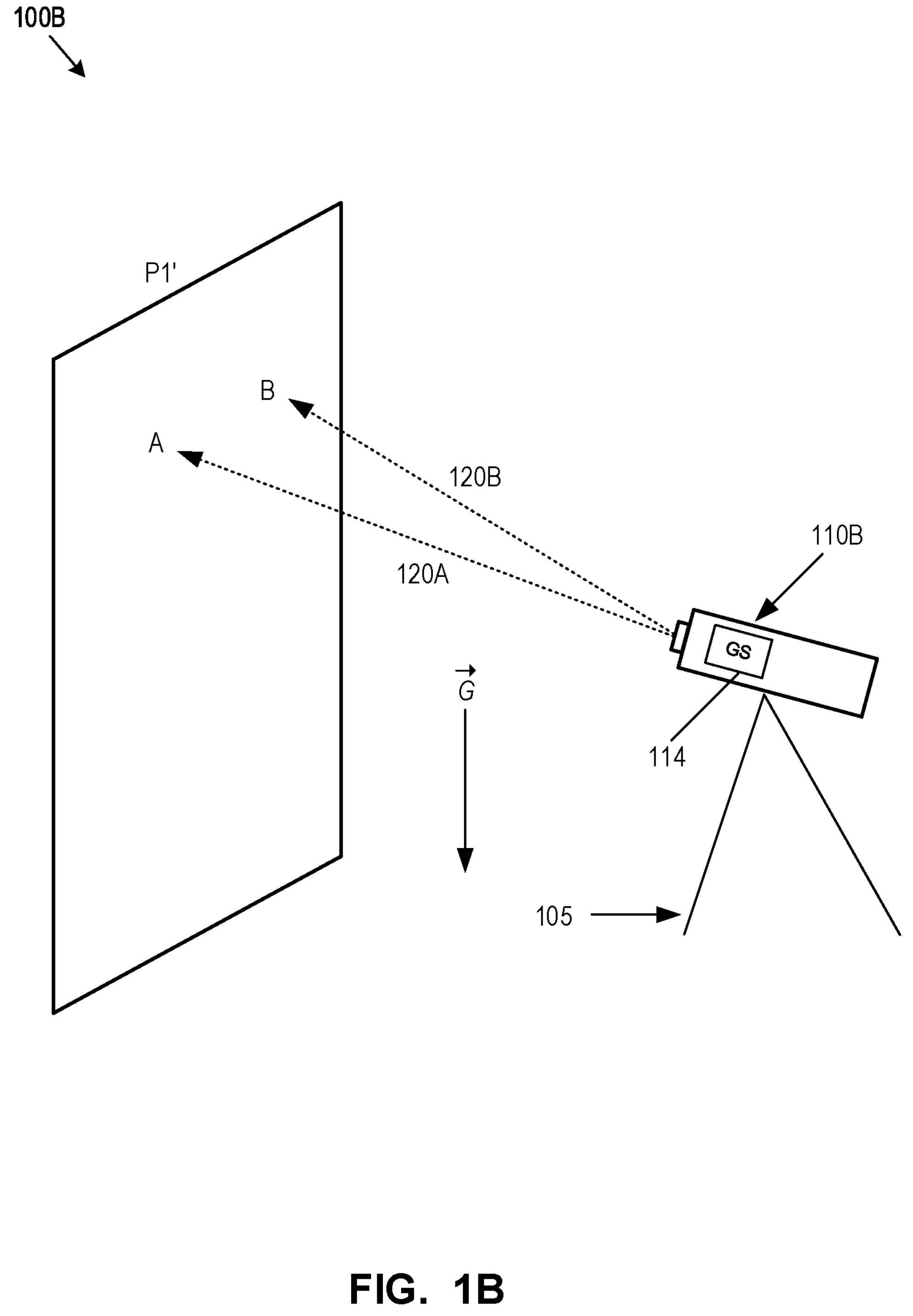

FIG. 1B

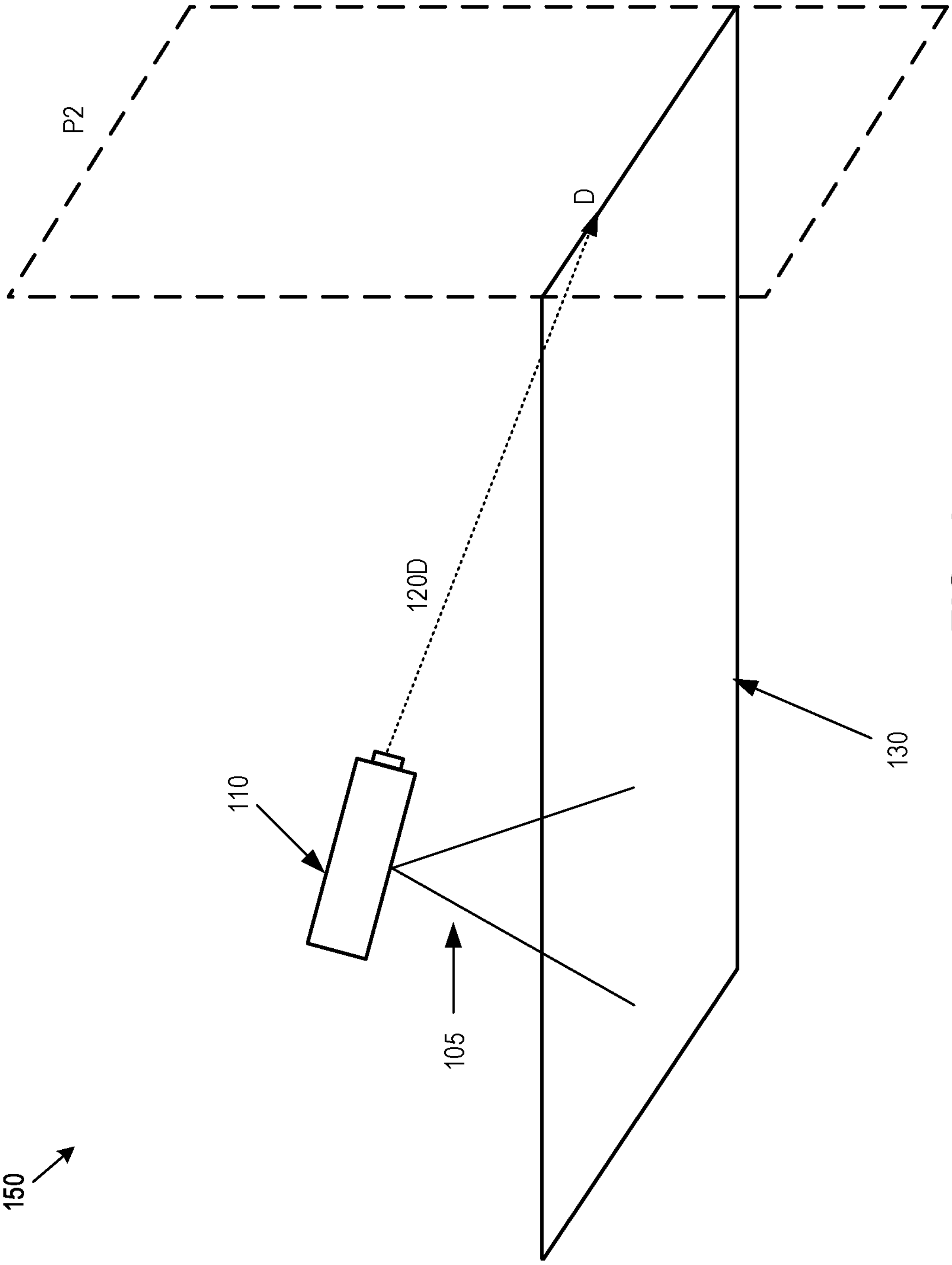

FIG. 2

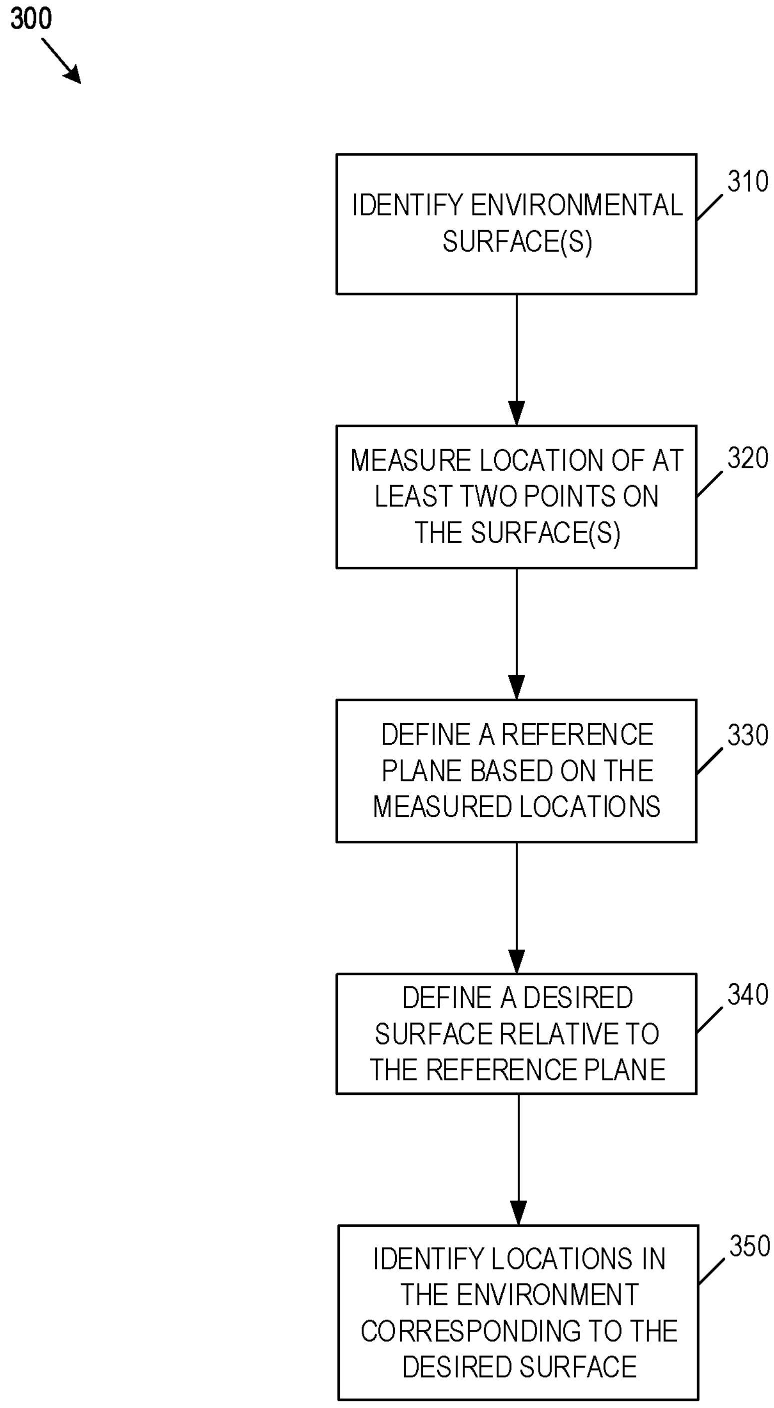
300
IDENTIFY ENVIRONMENTAL SURFACE(S)
310
MEASURE LOCATION OF AT LEAST TWO POINTS ON THE SURFACE(S)
320
DEFINE A REFERENCE PLANE BASED ON THE MEASURED LOCATIONS
330
DEFINE A DESIRED SURFACE RELATIVE TO THE REFERENCE PLANE
340
IDENTIFY LOCATIONS IN THE ENVIRONMENT CORRESPONDING TO THE DESIRED SURFACE
350

FIG. 3

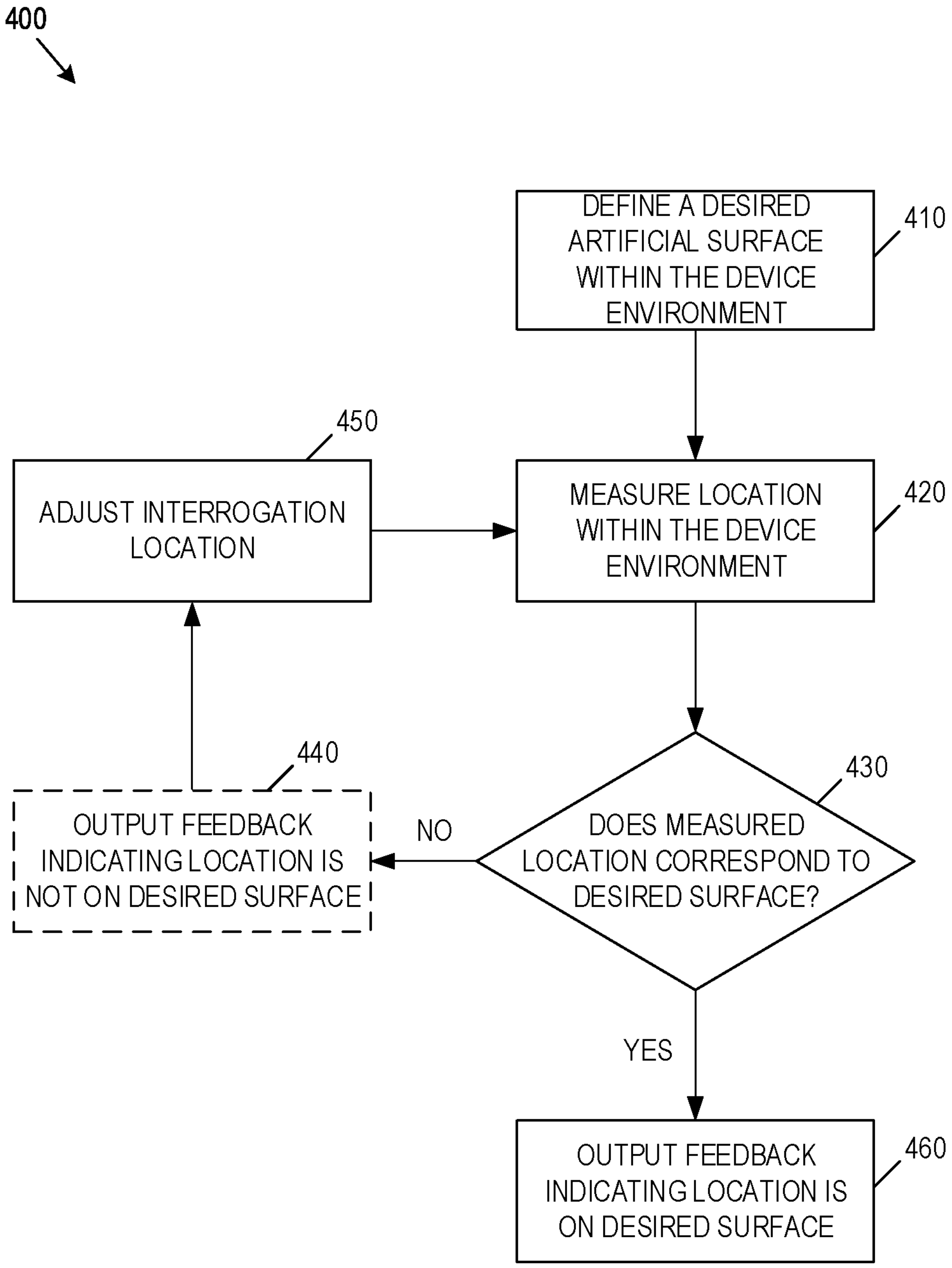
400
DEFINE A DESIRED ARTIFICIAL SURFACE WITHIN THE DEVICE ENVIRONMENT
410
450
ADJUST INTERROGATION LOCATION
MEASURE LOCATION WITHIN THE DEVICE ENVIRONMENT
420
440
430
OUTPUT FEEDBACK INDICATING LOCATION IS NOT ON DESIRED SURFACE
NO
DOES MEASURED LOCATION CORRESPOND TO DESIRED SURFACE?
YES
OUTPUT FEEDBACK INDICATING LOCATION IS ON DESIRED SURFACE
460

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2018/050394

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***G01S 17/48*** (2006.01)

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)
IPC: ALL

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases: QUESTEL ORBIT (FAMPAT)
Keywords: laser rangefinder/ radar; orientation/ position/ pose sensor; (environmental) mapping; identif+/ find+/ locat+/ determin+/ align+ reference plane/ surface/ wall/ object; spatial/ 3D model; identif+ location (of interest).

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US2017/0168160 A1 (METZLER et al.) 15 June 2017 (15-06-2017) * abstract; paras [1, 12, 85, 105, 123, 126-128, 133-134]; figs. 7-8, 10, 12 *	1-2, 4-8, 10-12, 14-19 3, 9, 13, 20
Y	US2013/0308120 A1 (PORTEGYS) 21 November 2013 (21-11-2013) * abstract; para [2]; claim 1; figs. 1-2; cited by applicant *	3, 9, 20
Y	US2015/0309174 A1 (GIGER) 29 October 2015 (29-10-2015) * paras [27, 52] *	13
A	US2017/0276485 A1 (PETTERSSON et al.) 28 September 2017 (28-09-2017) * whole document *	1-20
A	US2015/0153444 A1 (NICHOLS et al.) 04 June 2015 (04-06-2015) * whole document *	1-20

☐ Further documents are listed in the continuation of Box C.   ☑ 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
11 September 2018 (11-09-2018)

Date of mailing of the international search report
13 September 2018 (13-09-2018)

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2018/050394

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US2017168160A1	15 June 2017 (15-06-2017)	US2017168160A1 CN106872993A EP3182065A1	15 June 2017 (15-06-2017) 20 June 2017 (20-06-2017) 21 June 2017 (21-06-2017)
US2013308120A1	21 November 2013 (21-11-2013)	US2013308120A1 US8717579B2	21 November 2013 (21-11-2013) 06 May 2014 (06-05-2014)
US2015309174A1	29 October 2015 (29-10-2015)	US2015309174A1 US9470792B2 CN104913763A CN104913763B EP2918972A2 EP2918972A3	29 October 2015 (29-10-2015) 18 October 2016 (18-10-2016) 16 September 2015 (16-09-2015) 13 October 2017 (13-10-2017) 16 September 2015 (16-09-2015) 23 September 2015 (23-09-2015)
US2017276485A1	28 September 2017 (28-09-2017)	US2017276485A1 CN107218933A EP3222969A1	28 September 2017 (28-09-2017) 29 September 2017 (29-09-2017) 27 September 2017 (27-09-2017)
US2015153444A1	04 June 2015 (04-06-2015)	US2015153444A1 US9664784B2 EP3077847A1 WO2015126490A1	04 June 2015 (04-06-2015) 30 May 2017 (30-05-2017) 12 October 2016 (12-10-2016) 27 August 2015 (27-08-2015)