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(54) **Title:** LOCALIZING A SURVEYING INSTRUMENT IN RELATION TO A GROUND MARK

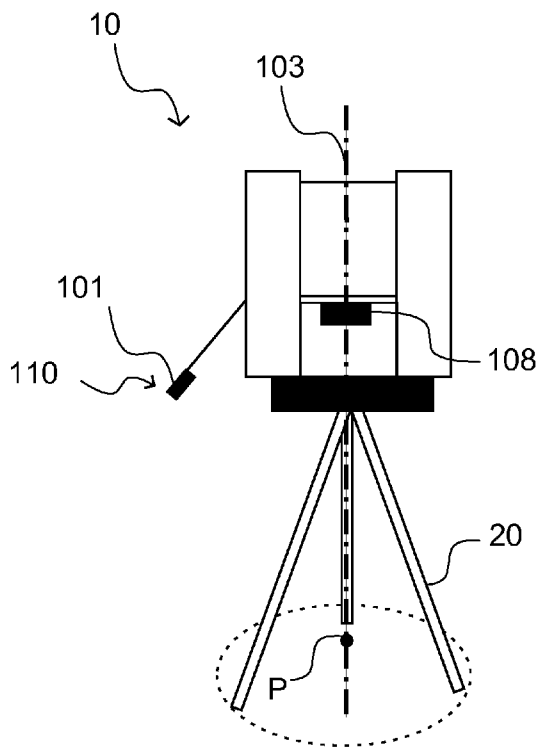


Fig. 1

(57) **Abstract:** A method is disclosed for localizing, in relation to a mark located at a ground level, a surveying instrument having a housing including at least one camera. The method comprises the steps of aligning the vertical rotational axis of the surveying instrument with the mark using a pointing device, capturing an image of the ground below the housing with the camera arranged in a known camera position and orientation, wherein the camera position is eccentric to the rotation center of the surveying instrument, identifying an object point corresponding to the mark in the captured image, measuring image coordinates of the object point in the captured image, and determining the height of the rotation center of said instrument above the ground based on the image coordinates and camera calibration data. Furthermore, a surveying instrument for performing the method is disclosed.

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LOCALIZING A SURVEYING INSTRUMENT IN RELATION TO A GROUND MARK

Technical field

The present invention relates to a method for localizing a surveying instrument, such as a total station, in a coordinate system, for instance a ground-based coordinate system. In particular, the present invention relates to a method for determining the height of a surveying instrument having a housing including at least one camera above a mark located at the ground level and a method for localizing the surveying instrument in relation to the mark.

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Background

The art of surveying involves the determination of unknown positions, surfaces or volumes of objects using measurements of angles and distances. In order to make these measurements, a surveying instrument frequently comprises an electronic distance measurement unit (EDM unit) which may be integrated in a theodolite, thereby forming a so-called total station. A total station combines electronic, optical and computer techniques and is furthermore provided with a computer or control unit with writable information for controlling the measurements to be performed and for storing data obtained during the measurements. A typical total station comprises a base with tribrach mounted on a tripod, an alidade mounted on the base for rotation about a vertical axis and a center unit mounted on the alidade for rotation about a horizontal axis. The center unit of the total station comprises a telescope and optical elements for aiming at a target. In particular, the center unit is provided with an EDM unit which operates generally in the direction of the optical axis of the center unit, i.e. along the line of sight. In, for example, WO 2004/057269 by the same applicant, such a total station is described in more detail. Preferably, the total station calculates the position of a target in a coordinate system, e.g. a fixed ground-based coordinate system. However, as the total station measures the position of the target relative to its own position, the position (or location) of the total station in the fixed ground-based coordinate system needs to be known.

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Throughout the application, the terms “geodetic instrument”, “surveying instrument” and “total station” will be used interchangeably. Further, the terms “position” and “location” will also be used interchangeably.

Hence, according to a first aspect of the present invention, a method
5 for localizing a geodetic instrument having a housing including at least one camera is provided. The method comprises the steps of aligning the vertical rotational axis of the surveying instrument with a mark located at a ground level using a pointing device, capturing an image of the ground below the housing with the camera arranged in a known camera position and
10 orientation, wherein the camera position is eccentric to the rotation center of the surveying instrument, identifying an object point corresponding to the mark in the captured image, measuring image coordinates of the object point in the captured image, and determining the height of the rotation center of the instrument above the ground based on the image coordinates and camera
15 calibration data.

According to a second aspect of the present invention, a geodetic instrument is provided. The geodetic instrument comprises a pointing device adapted to align the vertical rotational axis of the instrument with a mark located at a ground level and at least one camera adapted to capture an
20 image of the ground below the instrument. The camera is arranged in a known camera orientation and position, and the camera position is eccentric to a rotation center of the surveying instrument. The geodetic instrument further comprises an identifying unit adapted to identify an object point corresponding to the mark in the captured image, a measuring unit adapted to
25 measure image coordinates of the object point in the captured image and a processor adapted to determine the height of the rotation center of the surveying instrument above the ground based on the image coordinates and camera calibration data.

According to a third aspect of the present invention, there is provided a
30 computer program product comprising computer program code portions adapted to perform the method in accordance with the first aspect of the present invention when loaded and executed in a computer.

The present invention makes use of an understanding that, after aligning the nadir (or vertical rotational axis) of a surveying instrument or total
35 station with a mark located at a ground level, the height of the surveying instrument can be determined by means of a camera arranged in a position eccentric to a rotation center of the instrument. The present invention is

based on the use of trigonometry or triangulation to obtain the height of the instrument above the ground.

Using the eccentricity of a camera, the present invention makes use of an understanding that the height can be determined, in an image captured by the camera, from the image coordinates of an object point corresponding to the mark.

The position of the camera, i.e. the distance between the rotation center of the instrument and the camera, and the angular orientation of the camera, i.e. the angle formed between the image sensor of the camera (or alternatively the camera axis of the camera) and the line intersecting the rotation center of the instrument and the center of the image sensor of the camera, are calibrated (known) after assembly of the instrument. The calibration data of the camera may therefore be defined as a position and an angular orientation. However, the camera calibration data is not necessarily limited to these parameters and may comprise other parameters. For example, the angular orientation of the camera may be defined in terms of several angles related to the various rotational axis of the instrument. Such camera calibration data can be stored in the instrument.

The present invention is advantageous in that it provides an accurate and easy-to-implement method for determining the height and/or the coordinates of a total station in relation to a ground reference point.

According to an embodiment, the pointing device is an optical plummet calibrated in relation to the vertical rotational axis of the instrument. The optical plummet includes an eye piece for providing a view with a center mark that allows centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotational axis of the instrument with the mark.

According to another embodiment, the pointing device is a laser plummet including a laser pointer calibrated in relation to the vertical rotational axis of the instrument. The laser plummet provides a point or pattern visible on the ground that allows centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotation axis of the instrument with the mark.

According to an embodiment, the at least one camera is arranged in a position eccentric with respect to the nadir of the total station by means of a mechanical arrangement for folding out the camera from the instrument housing such that the field of view of the camera covers the area below the

instrument. The optical characteristics of the at least one camera and the camera position and orientation are selected such that the area between the legs of the tripod (at the ground level) can be viewed in the images captured by the camera.

- 5 Arrangement of the at least one camera far from the nadir of the instrument is beneficial since a broad view of the area between the legs of the tripod is provided. The at least one camera is preferably arranged such that the captured image provides a view of the ground as seen from the outside of the area defined by the legs of the tripod on which the instrument is mounted.
- 10 In such a configuration, the object points corresponding to the legs of the tripod in the captured images define the area in which the object point corresponding to the ground mark is located.

 Although the method of the present invention is defined using one camera in a single position and orientation, it will be understood that more than two images may be used to determine the height of the total station above the ground mark, thereby increasing accuracy in the determination of the height and/or the relative three-dimensional coordinates of the instrument. In particular, the instrument may be rotated around its rotational center from a first position to a second position, the rotation center being maintained fixed,

15 in order to capture a first image in a first camera position and a second image in a second camera position. Alternatively, the instrument may comprise two cameras of which a first camera is arranged in a first camera position and orientation and a second camera is arranged in a second camera position and orientation.

25 According to an embodiment, the method of the present invention comprises the step of determining the relative three-dimensional coordinates of the rotation center of the instrument in relation to the mark based on the image coordinates of the object point corresponding to the ground mark identified in the captured image and camera calibration data. In this context, it is noted that since the nadir of the instrument is aligned with the ground mark,

30 the two-dimensional coordinates of the rotation center of the instrument and the ground mark are the same or nearly the same.

 The method of the present invention may be implemented when setting up the total station over a known reference point, i.e. with the location of the mark located at the ground level known in a coordinate system. The method

35 of the present invention is used to determine the location of the total station in the coordinate system based on the relative coordinates of the total station in

relation to the known ground mark. In particular, the two-dimensional coordinates of the rotation center of the instrument, in a horizontal plane, are equivalent to the coordinates of the ground mark since the nadir of the total station is aligned with the ground mark in accordance with the present invention.

The present invention also provides a total station which comprises various means for carrying out the above-described method.

In addition, the present invention can be implemented in a computer program that, when executed, performs the inventive method in a surveying instrument. The computer program may, for example, be downloaded into a surveying instrument as an upgrade. As will be understood, the inventive method can be implemented for a surveying instrument using software, hardware or firmware, or a combination thereof, as desired in view of the particular circumstances.

Brief description of the drawings

In the following detailed description, reference is made to the accompanying drawings, on which:

Figure 1 is a view of a surveying instrument according to an embodiment of the present invention;

Figure 2 schematically shows the parameters of the surveying instrument used in the method of the present invention;

Figure 3 is a general outline of the inventive method; and

Figure 4 shows schematically a geodetic instrument according to the present invention.

Detailed description

Figure 1 illustrates schematically a total station 10 mounted on a tripod 20. The total station comprises at least one camera 110 positioned in a camera position 101 for capturing images of the ground below the instrument (or housing of the total station). According to the present invention, an object point relating to a mark located at the ground level, denoted by the letter P in the figures, is identified in images captured by the camera of the surveying instrument. The total station further comprises a pointing device 108, which for example may be an optical plummet or a laser plummet, for aligning the nadir 103 of the instrument with the mark P located at the ground level.

With reference to both Figures 1 and 2, there is shown at least one camera sensor 107, such as a CMOS camera or a CCD, in the position 101 for capturing an image centered about a camera axis 102. The camera axis 102 is perpendicular to the camera sensor 107 or plane in which the image is formed on the sensor. The images are formed on the camera sensor 107 by means of an optical system such as a lens 106. The camera 110 in the position 101 has a camera center, or projection center, indicated by O'.

As illustrated in Figure 2, the camera center O' and a rotational center 104 of the surveying instrument form an horizontal line denoted 105 having a length d. The position 101 of the camera center O' is eccentric with respect to the rotation center 104 of the instrument and the eccentricity of the position 101 is determined by the distance d to the rotational center.

It is noted that the rotation center O, as shown in Figure 2, is located along the nadir of the instrument and represents the center of rotation for the camera. The rotation center O represented in Figure 2 is not necessarily the center of the instrument as normally defined by the intersection between the vertical and horizontal axis of the telescope of the center unit of the surveying instrument (see feature 414 in Figure 4). It is noted that the position of the center O 104 for rotation of the camera in relation to the position of the center 414 of the instrument may be known from calibration.

The camera sensor is also characterized by its orientation, i.e. the angle α formed between the camera axis 102 and the line 105, which corresponds to the angle at which the camera is oriented to view the area located between the legs of the tripod.

The camera optical axis should ideally be perpendicular to the plane of the camera sensor 107 and the optical system should be free from distortions or aberrations. However, this is not the case in practice and this may be taken into account by calibration of the camera.

It is noted that, for simplicity, Figures 1 and 2 show views of the surveying instrument in two dimensions only. However, a person skilled in the art would understand that the elements and features shown in Figures 1 and 2 may be defined in terms of other angles than those shown in the figures. For example, the orientation of the camera may also be defined by the angle formed by the image plane defined by the camera sensor around the arm on which the camera is arranged.

According to the present invention, the pointing device 108 is adapted to align the nadir of the instrument with the ground mark, thereby forming a

right angle triangle. The right angle is formed between the line intersecting the center O of the instrument (for rotation of the camera) and the ground mark after the alignment with the pointing device and the line 105. Once the nadir is aligned with the ground mark, an image is captured by the camera sensor, with the camera center located in a camera position O' eccentric to the location O of the rotation center of the surveying instrument and having a specific camera orientation. A mark P located at the ground level is selected by identifying an object point in the captured image.

Once the mark has been selected by identification of the object point in the captured image, image coordinates of the object point in the captured image are measured.

Then, the height of the rotation center O of the surveying instrument above the ground, i.e. in relation to or above the ground mark, is determined based on the image coordinates and camera calibration data.

In particular, the image coordinates provide the angle β formed between the line 105 and the direction 112 from the camera to the ground mark (i.e. the line intersecting the center O' of the camera and the ground mark P). In particular, the camera 110 (i.e. the camera sensor with its optical system) is preferably calibrated such that every pixel of the camera sensor is related to an angle. Once the angle β has been determined, the height h of the instrument above the ground may be calculated using trigonometry. The height h may be calculated using the following equation:

$$h = d \times \tan(\beta) \quad (1).$$

General steps of the method according to the present invention are outlined in figure 3. The method is performed in a surveying instrument comprising at least one camera and a pointing device 108 and starts with aligning, in a step S301, the nadir of the instrument with a mark located at the ground level using a pointing device. In step S302, an image of the ground below the instrument is captured by the camera arranged in a known camera position and orientation, the camera position being eccentric to the rotation center of the surveying instrument. In step S303, an object point corresponding to a ground mark is identified in the captured image, which may be a snapshot or a frame of a video feed captured by the camera. For example, the mark may be identified by selection by a surveyor clicking on a screen showing the image captured by the camera, or in any other suitable

point has been identified in the second captured image, second image coordinates of the object point in the second image are measured and the height of the instrument may be determined based on the second image coordinates and camera calibration data corresponding to the second camera position and orientation. Capturing of a plurality of images in different positions may be implemented by means of a single camera and rotation of the instrument to different positions or by means of more than one camera arranged at different positions.

According to the present invention, the two-dimensional coordinates, in a horizontal plane, of the total station are equal to the two-dimensional coordinates of the mark located at the ground level since the nadir of the instrument is aligned with the ground mark.

After determination of the height of the instrument in relation to the mark in accordance with the method of the present invention, the three-dimensional coordinates of the rotation center in relation to the mark can then be used in subsequent geodetic measurements performed by the instrument to relate instrument measurements to the coordinates of the ground mark.

According to an embodiment, the point device is an optical plummet calibrated in relation to the vertical rotational axis of the instrument. The optical plummet includes an eye piece for providing a view with a center mark that allows centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotational axis of the instrument with the mark.

According to another embodiment, the pointing device is a laser plummet including a laser pointer calibrated in relation to the vertical rotational axis of the instrument. The laser plummet provides a point or pattern on the ground that allows centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotation axis of the instrument with the mark.

To further localize the surveying instrument, a step of orienting the horizontal pointing direction of the surveying instrument may be carried out by aiming at a reference point located at a remote position from the surveying instrument. The reference point used for orienting the pointing direction is positioned at a known location in the coordinate system. The orientation of the surveying instrument to a known control point together with the determination of the relative three-dimensional coordinates (and in particular

CLAIMS

1. A method for localizing, in relation to a mark located at a ground level, a surveying instrument having a housing including at least one camera, said method comprising:
- 5 aligning the vertical rotational axis of the surveying instrument with said mark using a pointing device;
- capturing an image of the ground below the housing with said camera arranged in a known camera position and orientation, said camera position being eccentric to the rotation center of the surveying instrument;
- 10 identifying an object point corresponding to the mark in the captured image;
- measuring image coordinates of the object point in the captured image; and
- 15 determining the height of the rotation center of said instrument above the ground based on the image coordinates and camera calibration data.
2. The method of claim 1, wherein said pointing device is an optical plummet calibrated in relation to the vertical rotational axis of said instrument, said optical plummet including an eye piece for providing a view with a center mark that allows centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotational axis of said instrument with said mark.
- 20
3. The method of claim 1, wherein said pointing device is a laser plummet including a laser pointer calibrated in relation to the vertical rotational axis of said instrument, said laser plummet providing a point or pattern on the ground, said point or pattern allowing centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotation axis of said instrument with said mark.
- 25
- 30
4. The method of any one of the preceding claims, further comprising determining the relative three-dimensional coordinates of the rotation center of said instrument in relation to said mark based on the image coordinates and camera calibration data.
- 35

5. The method of any one of the preceding claims, wherein the mark located at the ground level is positioned at a known location in a coordinate system.
- 5 6. The method of any one of the preceding claims, wherein the calibration data comprises the orientation and position of the camera in relation to the rotation center of said instrument.
7. The method of any one of the preceding claims, wherein the object
10 point is identified in the images by means of operator selection or automatic image analysis.
8. The method of any one of the preceding claims, wherein identifying the object point corresponding to said mark comprises :
15 capturing a first image while the mark is illuminated by means of a light source,
capturing a second image with the light source turned off, and
subtracting the first and second image from one another in order to produce a difference image on which an object point representative of said mark is
20 identified.
9. The method of any one of the preceding claims, further comprising:
arranging a structured object on said mark for facilitating identifying of the object point in the captured images.
25
10. A computer program product comprising computer program code portions adapted to perform the method of any one of claims 1-9 when loaded and executed in a computer.
- 30 11. A surveying instrument, comprising:
a pointing device adapted to align the vertical rotational axis of said instrument with a mark located at a ground level;
at least one camera adapted to capture an image of the ground below the instrument, said camera being arranged in a known camera orientation
35 and position, said camera position being eccentric to a rotation center of the surveying instrument;

an identifying unit adapted to identify an object point corresponding to said mark in the captured image;

a measuring unit adapted to measure image coordinates of the object point in the captured image; and

5 a processor adapted to determine the height of the rotation center of the surveying instrument above the ground based on the image coordinates and camera calibration data.

12. The surveying instrument of claim 11, wherein said pointing device is an optical plummet calibrated in relation to the vertical rotational axis of said instrument, said optical plummet including an eye piece for providing a view with a center mark that allows centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotational axis of said instrument with said mark.

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13. The surveying instrument of claim 11, wherein said pointing device is a laser plummet including a laser pointer calibrated in relation to the vertical rotational axis of said instrument, said laser plummet providing a point or pattern on the ground, said point or pattern allowing centering of the total station over the mark located at the ground level by mechanically moving the total station, thereby aligning the vertical rotation axis of said instrument with said mark.

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14. The surveying instrument of any one of claims 11-13, wherein the mark located at the ground level is positioned at a known location in a coordinate system.

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15. The instrument of any one of claims 11-14, wherein the identifying unit is implemented as a cursor movable across the displayed images, using image processing software or using a touch display where the object point can be identified by clicking or tapping on the display.

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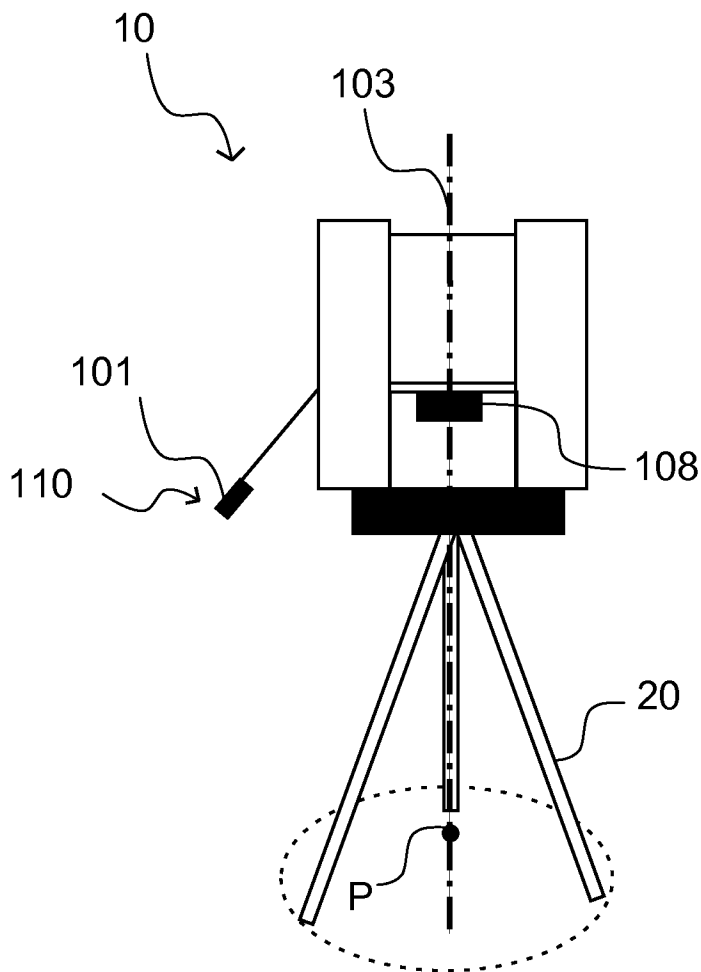
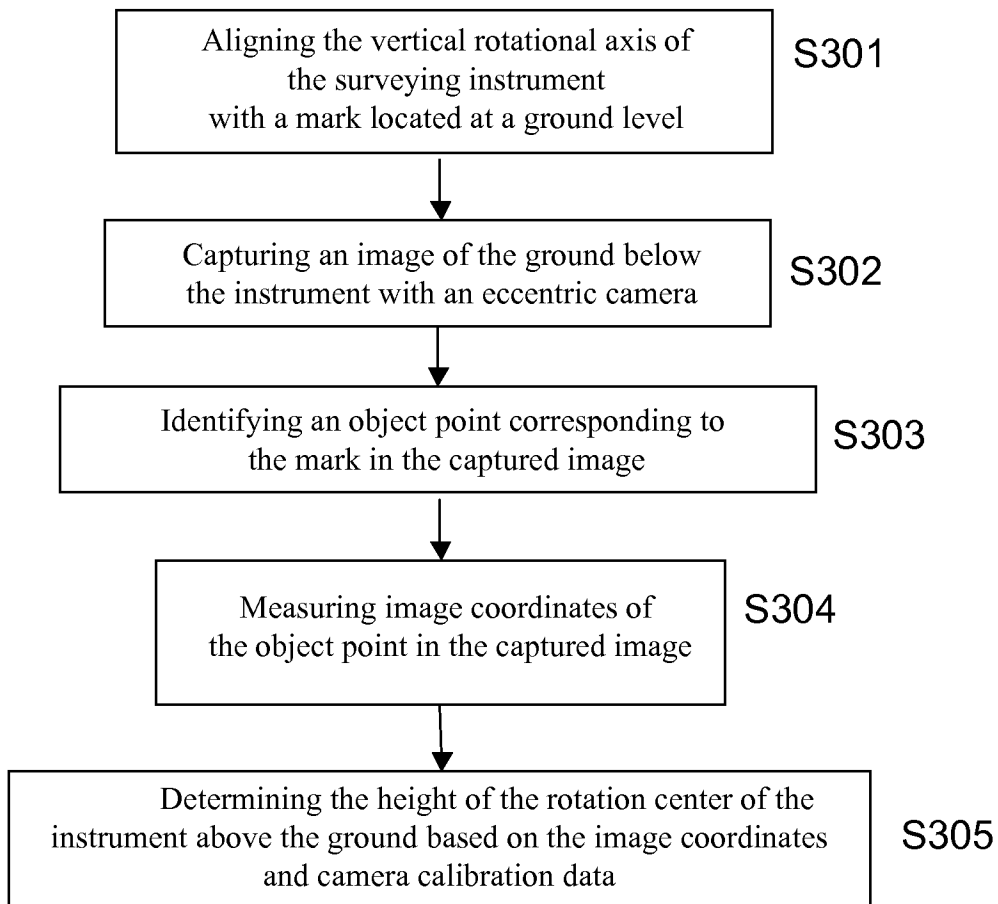


Fig. 1

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*Fig. 3*

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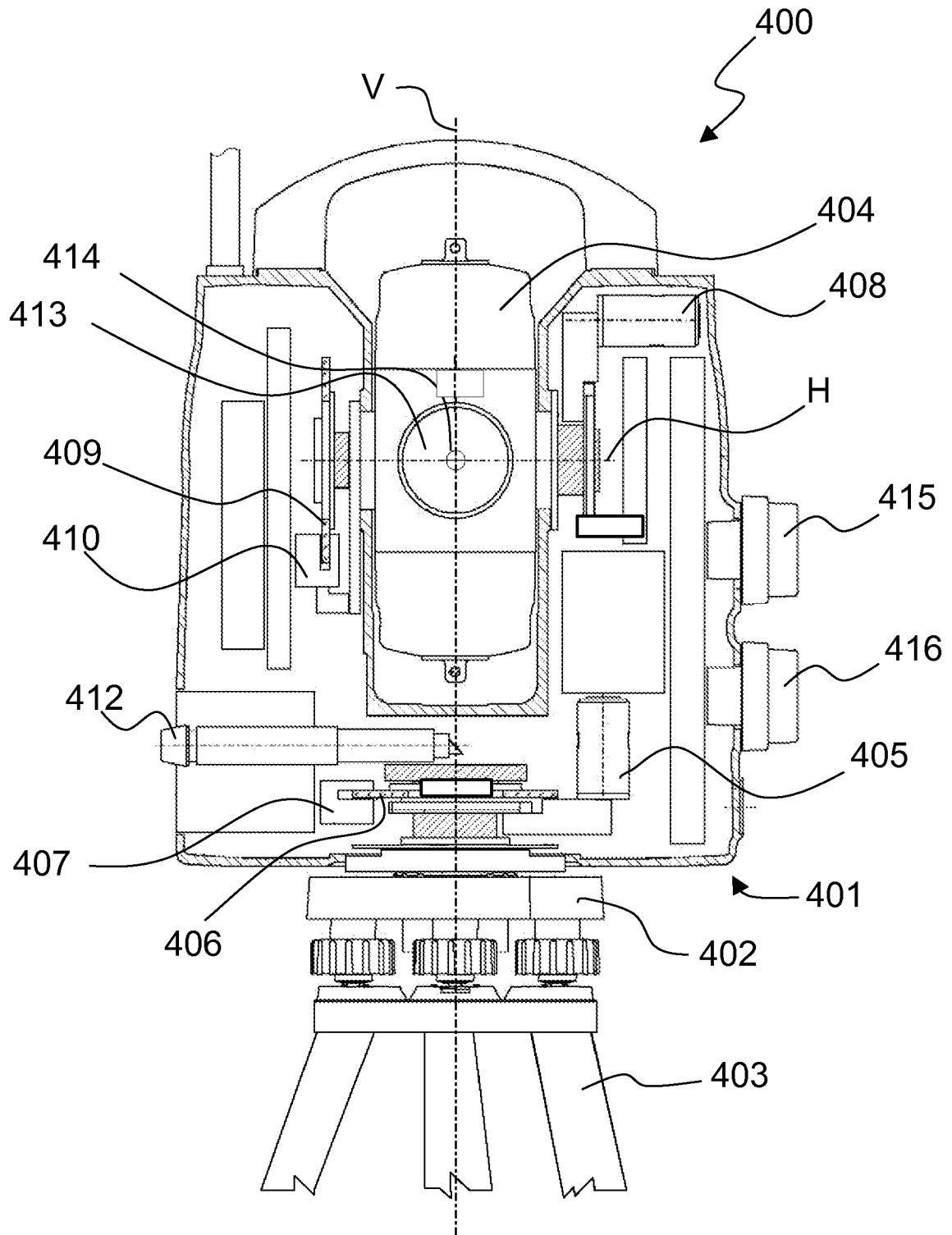


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/058183

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01C1/04 G01C15/00

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)
G01C

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 practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 5 949 548 A (SHIRAI MASAMI [JP] ET AL) 7 September 1999 (1999-09-07) the whole document	1-15

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search

3 November 2008

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/058183

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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