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(54) **POSITIONAL ACCURACY USING GROUND PENETRATING RADAR**

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(51) **Int. Cl.**
G01S 13/88 (2006.01)

(52) **U.S. Cl.**
CPC ***G01S 13/885*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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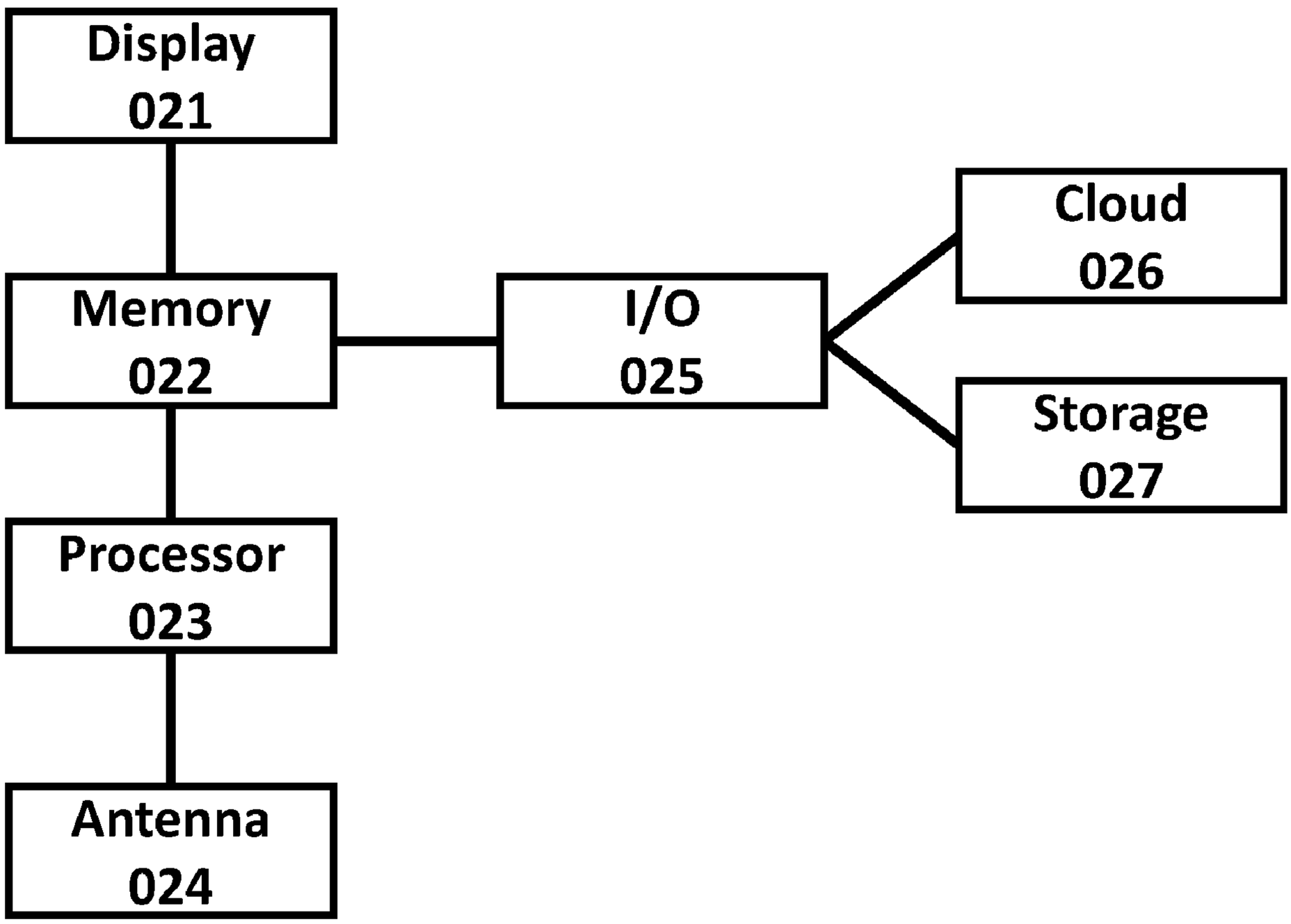
(57) **ABSTRACT**

A system for obtaining improved position accuracy with ground penetrating radar includes a position locating device capable of detecting objects, such as substrate objects, at at least two points along an extent thereof. Methods for its use include collecting, modeling, and comparing detected radar data with other detected radar data and/or previously input data and/or assumed and/or predicted data.

20 Claims, 6 Drawing Sheets



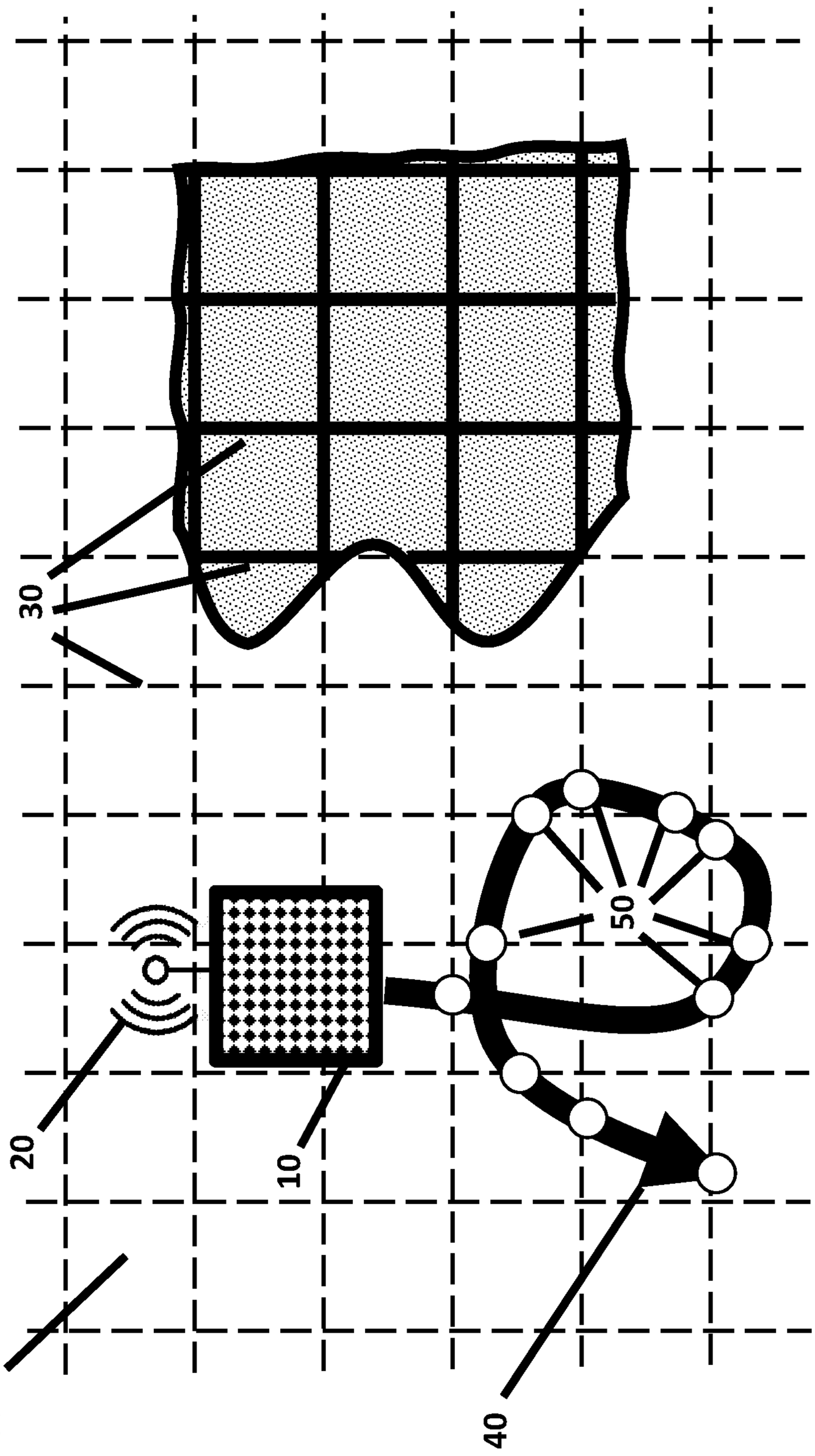


Fig. 1

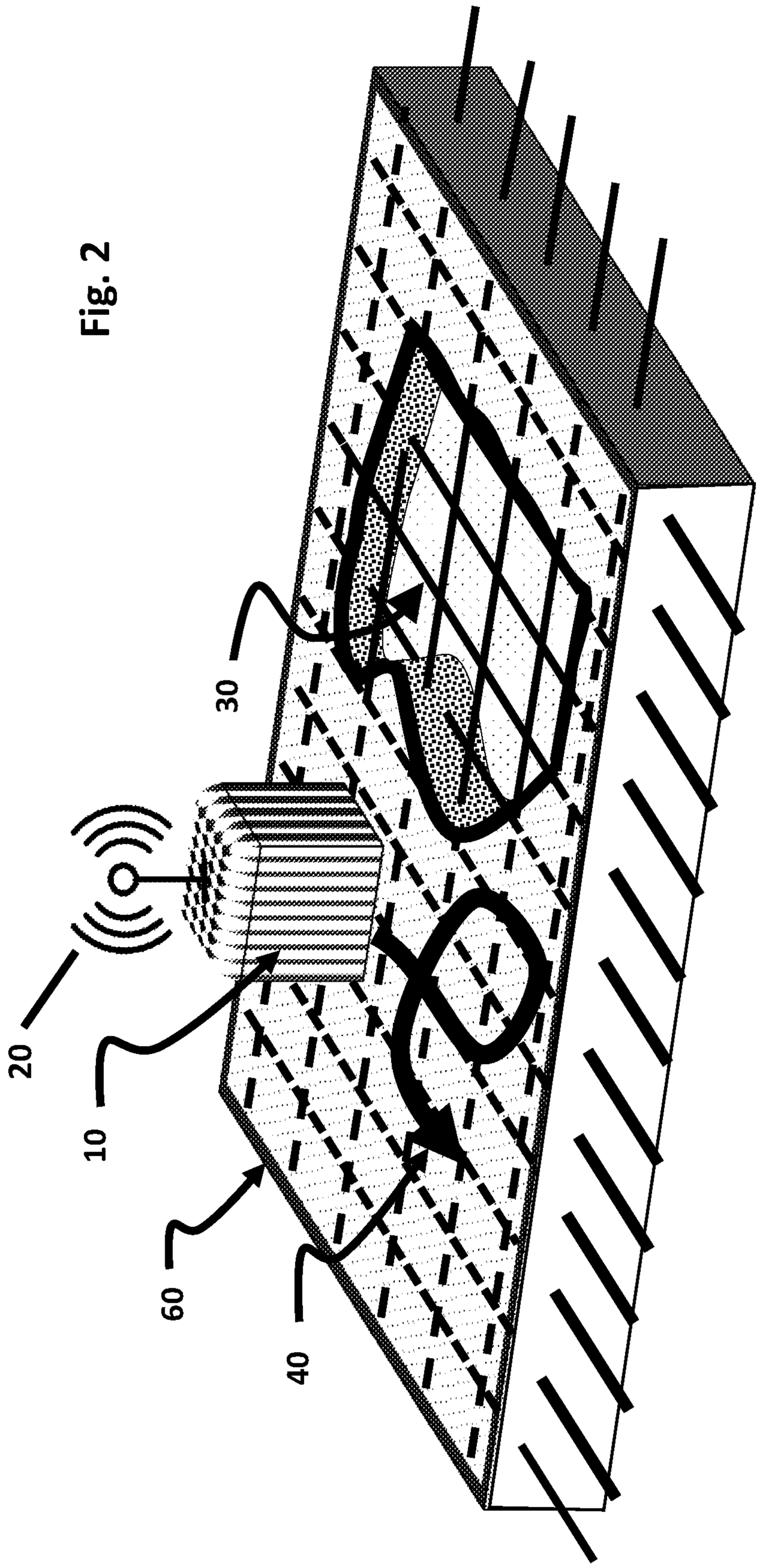


Fig. 2

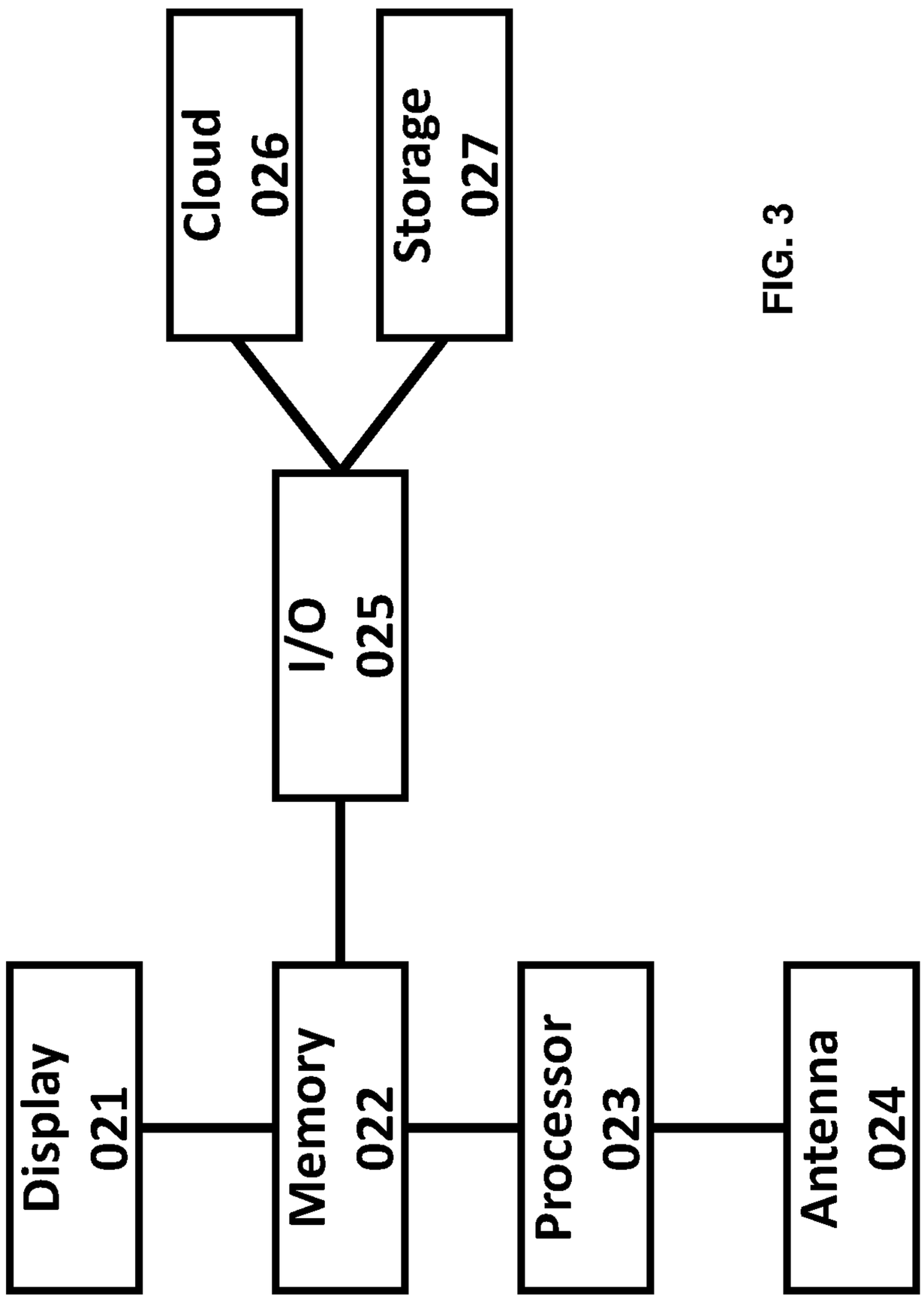

Cloud
026
Storage
027
I/O
025
Display
021
Memory
022
Processor
023
Antenna
024

FIG. 3

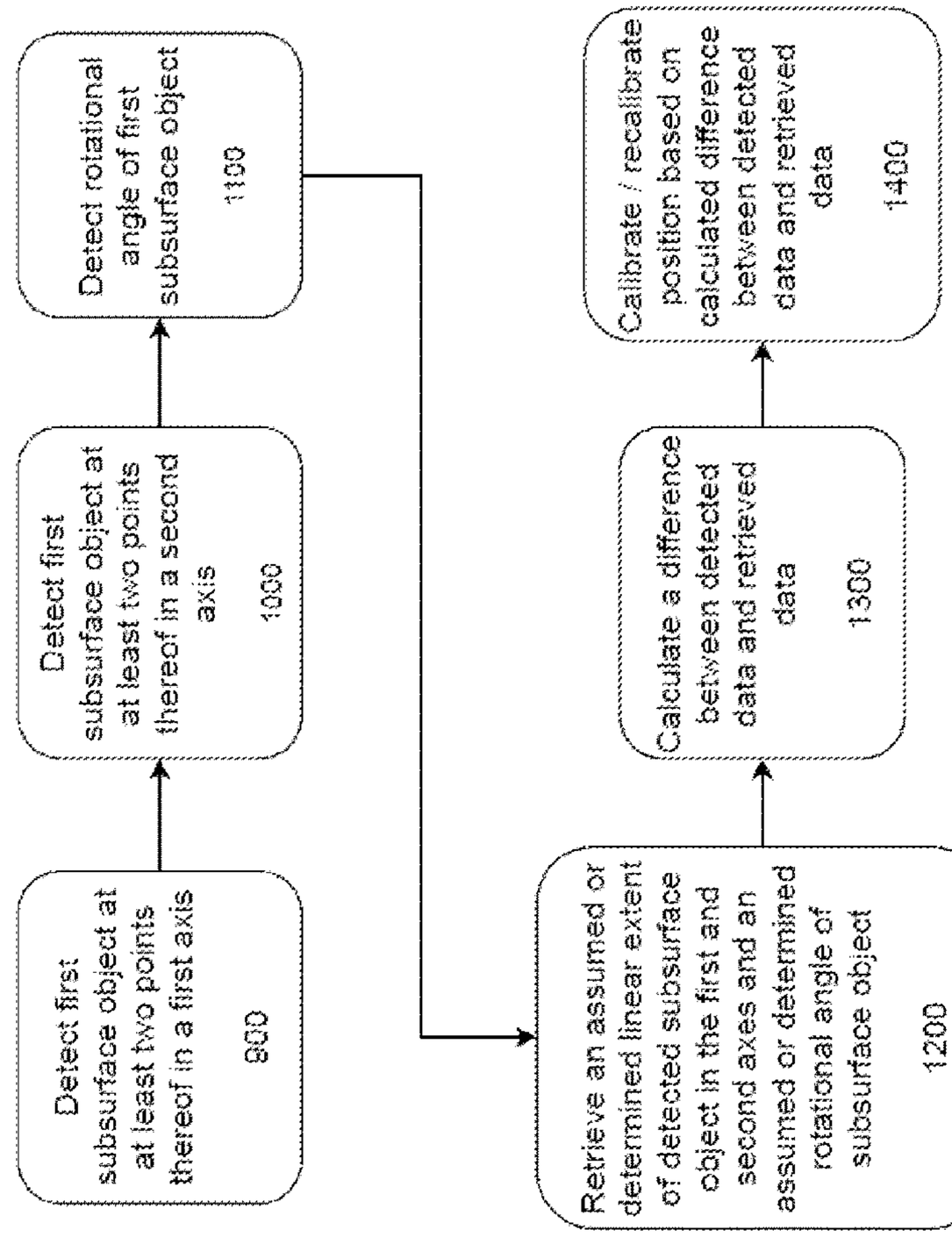

Detect first subsurface object at at least two points thereof in a first axis
800
Detect first subsurface object at at least two points thereof in a second axis
1000
Detect rotational angle of first subsurface object
1100
Retrieve an assumed or determined linear extent of detected subsurface object in the first and second axes and an assumed or determined rotational angle of subsurface object
1200
Calculate a difference between detected data and retrieved data
1300
Calibrate / recalibrate position based on calculated difference between detected data and retrieved data
1400

Fig. 5

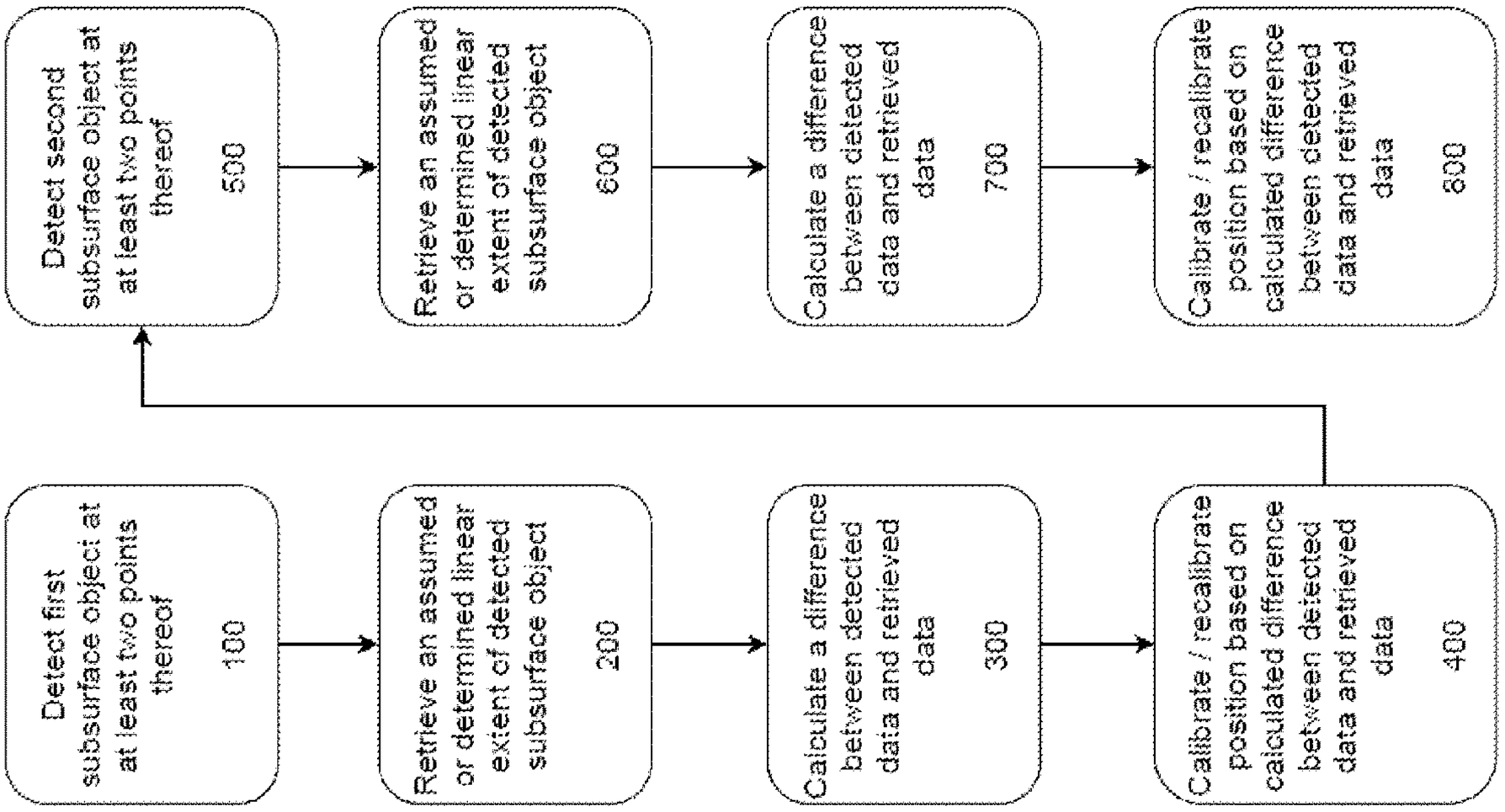

Detect first subsurface object at at least two points thereof
100
Retrieve an assumed or determined linear extent of detected subsurface object
200
Calculate a difference between detected data and retrieved data
300
Calibrate / recalibrate position based on calculated difference between detected data and retrieved data
400
Detect second subsurface object at at least two points thereof
500
Retrieve an assumed or determined linear extent of detected subsurface object
600
Calculate a difference between detected data and retrieved data
700
Calibrate / recalibrate position based on calculated difference between detected data and retrieved data
800

Fig. 4

Fig. 6

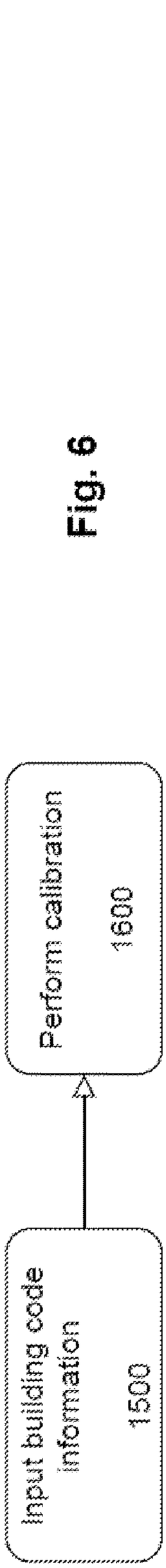

Input building code information
1500
Perform calibration
1600
Estimate device position and orientation
1700
Detect one set of subsurface radar data
1800
Create inverse model of radar data
1900
Calculate best fit pose between inverse model and known, determined, or assumed subsurface radar data
2100
Map best fit pose to likely device position
2200
Predict position of anticipated subsequently-detected set of radar data
2300
Compare inverse model with known, determined, or assumed subsurface radar data
2000

Fig. 7

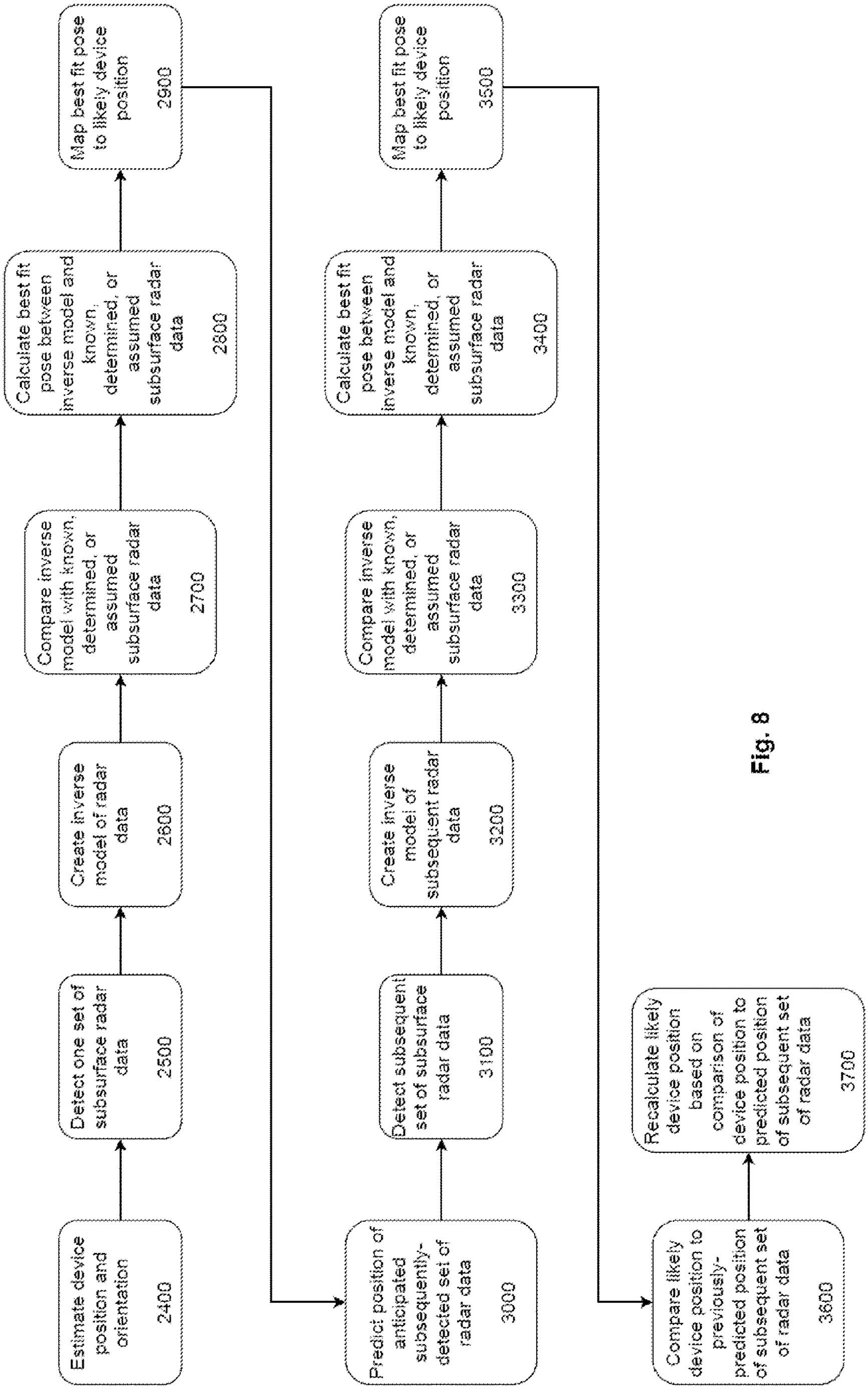

Estimate device position and orientation
2400
Detect one set of subsurface radar data
2500
Create inverse model of radar data
2600
Compare inverse model with known, determined, or assumed subsurface radar data
2700
Map best fit pose to likely device position
2900
Calculate best fit pose between inverse model and known, determined, or assumed subsurface radar data
2800
Predict position of anticipated subsequently-detected set of radar data
3000
Detect subsequent set of subsurface radar data
3100
Create inverse model of subsequent radar data
3200
Compare inverse model with known, determined, or assumed subsurface radar data
3300
Map best fit pose to likely device position
3500
Calculate best fit pose between inverse model and known, determined, or assumed subsurface radar data
3400
Compare likely device position to previously-predicted position of subsequent set of radar data
3600
Recalculate likely device position based on comparison of device position to predicted position of subsequent set of radar data
3700

Fig. 8

POSITIONAL ACCURACY USING GROUND PENETRATING RADAR

FIELD OF THE DISCLOSED TECHNOLOGY

The disclosed technology relates generally to position determination, and more specifically, to improving position determination using a combination of subsurface structure location determination and Ground Penetrating Radar (GPR) scanning devices.

BACKGROUND

Accurately knowing the position and orientation, or Pose, of an object is vital in myriad applications, from automated vacuum cleaners to space shuttles. An object's Pose—its 3D position (X,Y,Z) and its orientation (Pitch, Roll and Yaw)—comprise the six Degrees of Freedom (6DoF) needed to track a solid object as it moves through space. Many methods can be used to track Pose, including cameras, Inertial Measurement Units (IMUs) or LiDAR.

One of the main challenges of calculating Pose for most of these technologies is "drift", a slow change and/or error in determined position. Errors due to drift range from mistakes in videogames to errors in missile targeting. Typical methods for compensating for drift including use of an external reference (a "Global Reference"), such as a camera or a set of sensors in fixed locations surrounding the tracked target. Additionally, good positioning typically must rely on complimentary methods to compensate for the failure modes of various forms of Global References. For example, if a camera is jostled while acting as a Global Reference, all subsequent Pose estimations will likely require recalibration.

Thus, there is a need for limiting the failure modes of the current Pose estimation methods, such as when applied to GPR surveys. This and other problems are solved by embodiments of the disclosed technology, as described below.

SUMMARY OF THE DISCLOSED TECHNOLOGY

A position locating device (hereafter a PLD) of embodiments of the disclosed technology includes one or more ground penetrating radar transceivers and one or more location determining systems. The device is configured such that detection, by way of a ground penetrating radar transceiver, of a first subsurface object at, at least, two different points thereon, is used to correct (calibrate and/or recalibrate) a pose estimation of the PLD. The at least two different points, in embodiments, extend in a direction other than a path of travel of the PLD during the detection. The pose correction is, in some embodiments, based on an assumed or determined linear or predictable extent (hereafter "linear extent") of the first subsurface object.

In various embodiments, the direction of the extent of the at least two different points may be perpendicular to the path of travel of the PLD during the detection. A longest extent of the first subsurface object may be, in embodiments, linear and at an angle different from the path of travel of the PLD.

The device may be further configured such that following the aforesaid detection of the first subsurface object and the aforesaid first pose correction, a subsequent detection, by way of the ground penetrating radar transceiver, of a second subsurface object from at least two different points thereon is used to further correct the pose of the PLD relative to the first and second subsurface objects. The subsequently detected subsurface object from at least two different points may extend in a direction other than a path of travel of the PLD during the subsequent detection. In some embodiments, the pose correction may be based on an assumed or determined linear extent of the first and second subsurface objects.

In some embodiments, a longest extent of one of the first and second subsurface objects may be perpendicular relative to the path of travel of the PLD while a longest extent of the other subsurface object may be at a non-right angle relative there-to. This may be the case both during the pose correction occurring when the PLD travels over the first subsurface object and during the pose correction occurring when the PLD travels over the second subsurface object.

The process of pose correction, in some embodiments, includes detections of the subsurface object along a first axis and a second axis, followed by a determination of a location of the PLD relative to each of the first and second axes. In embodiments, the first axis is perpendicular to the second axis and the subsurface axis is known, determined, and/or assumed to be linear. Each of said first axis and the second axis may be located along a longest linear extent and/or a shortest linear extent and/or a diagonal linear extent of said subsurface object. "Diagonal linear extent" is defined as a linear extent at an acute angle relative to a longest linear extent and/or a shortest linear extent and/or a linear extent of a known or detected length. The determined location may be used, in various embodiments, to detect the pose of the PLD independently and/or to confirm and/or specify a predetermined or predicted position or path thereof.

In some embodiments, the pose correction may further require a rotational angle of the PLD relative to the subsurface object or objects.

In some embodiments, the assumed linear extent of the subsurface object may be based on known information from for example building codes, BIM models or reconstructed GPR images inputted into the PLD.

A method of using the PLD, in embodiments, includes the steps of detecting, in a first detection, a first subsurface object at, at least, two different points thereon, and of correcting the pose estimation of the PLD relative to the first subsurface object. In various embodiments, the at least two different points extend in a direction other than a path of travel of the device during the step of first detection, and the step of correction is performed using the at least two different points. The step of correction may be based on an assumed or determined linear extent of the subsurface object.

During the step of first detection, the at least two different points may extend in a direction perpendicular to the path of travel of the PLD. Furthermore, in embodiments, a longest extent of the first subsurface object may be perpendicular or at a non-right angle relative to the path of travel of the PLD during the step of first detection.

In embodiments of the disclosed technology, the above-described method further includes the subsequent steps of further detecting, in a second detection, a second subsurface object at, at least, two different points thereof, and further correcting a pose of the PLD relative to the first and second subsurface objects. The at least two different points detected during the step of second detection may extend in a direction other than a path of travel of the PLD during one or both of the steps of first detecting and second detecting. The step of further correcting may use the at least two different points detected during the second step of detection and/or may be

based on an assumed or determined linear extent of the first subsurface object and/or the second subsurface object.

In some embodiments, a longest extent of one of the first and second subsurface objects may be perpendicular relative to the path of travel of the PLD while a longest extent of the other subsurface object may be at a non-right angle relative there-to. This may be the case both during the step of pose correction occurring when the PLD travels over the first subsurface object and during the step of correction occurring when the PLD travels over the second subsurface object.

In further embodiments, the aforementioned steps of pose correction may each include the steps of detecting a respective subsurface object in a first axis and in a second axis, and determining a location of the PLD relative to each of the detected first axis and the detected second axis.

In embodiments, the two axes are perpendicular to each other and the respective subsurface object is known, determined, and/or assumed to be linear, such that each of the first and second axis is located along a longest linear extent and/or a shortest linear extent and/or a diagonal linear extent of respective subsurface object. The determined location, in various embodiments of the disclosed technology, is used to detect a pose of the PLD independently and/or to confirm and/or specify a predetermined or pre-detected position thereof.

In embodiments, the PLD further includes at least one antenna. The aforementioned steps of pose correction may each further include a step of detecting a rotational angle of the PLD relative to the respective subsurface object by way of the antenna.

The PLD, in various embodiments, further includes an input device. The above-described method, in some embodiments, includes a step of inputting known building code information into the input device. The known building code information may include at least an assumed linear extent of each respective subsurface object mentioned above.

Described differently, a method of correcting for position errors of a PLD of embodiments of the disclosed technology may include the following steps: determining a substation pose of a PLD; detection, in a first step of detection, by way of a ground penetrating radar transceiver of the PLD, at least one set of subsurface radar data; creating, using the at least one set of subsurface radar data, an inverse model of reflections and/or diffractions included therein; comparing the inverse model with known, determined, and/or assumed subsurface data; calculating a best-fit pose between the inverse model and the known, determined, and/or assumed subsurface data; mapping the best-fit pose to a most likely pose of the PLD; and predicting at least one most likely position of at least one anticipated subsequent set of subsurface radar data to be detected, in at least a second step of detection, by way of the ground penetrating radar transceiver of the PLD.

"Inverse model" is defined as an analytical and/or numerical model created based on a difference between a first set and a second set of data, the first set of data being detected and the second set of data being considered "ideal". "Inverse model" is further defined as an analytical and/or numerical model created based on a difference between a first set and a second set of data, the first set of data being detected and the second set of data being subsequently detected. "Subsurface data" is defined as data relating to a substance, interior, and/or internal makeup of at least a portion of a structure and/or location.

The method, in various embodiments, may further include the following steps: detecting, in a second step of detection, at least one subsequent set of subsurface radar data; creating, using the at least one subsequent set of subsurface radar data, an inverse model of reflections and/or diffractions included therein; comparing the inverse model with known, determined, and/or assumed subsurface data; calculating a best-fit pose between the inverse model and the known, determined, and/or assumed subsurface data; mapping the best-fit pose to a most likely pose of the PLD; comparing most likely position determined based on the at least one subsequent set of subsurface radar data with the previously-predicted most likely pose of the PLD; determining, based on the comparison with the previously-predicted most likely position, a most likely pose of the PLD; and predicting, based on the last-determined most likely pose of the PLD, at least one most likely position of at least one additional anticipated subsequent set of subsurface radar data to be detected, in at least a third detection, by way of the ground penetrating radar transceiver of the PLD.

Any device or step to a method described in this disclosure can comprise or consist of that which it is a part of, or the parts which make up the device or step. The term "and/or" is inclusive of the items which it joins linguistically and each item by itself.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a top plan of elements involved in obtaining improved positional accuracy with ground penetrating radar of an embodiment of the disclosed technology.

FIG. **2** shows a front right side elevation view of the elements of FIG. **1** of an embodiment of the disclosed technology.

FIG. **3** shows a flowchart of components of a PLD for obtaining improved positional accuracy with ground penetrating radar of an embodiment of the disclosed technology.

FIG. **4** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using multiple detection steps and multiple retrieval steps of an embodiment of the disclosed technology.

FIG. **5** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using a single detection step and a single retrieval step of an embodiment of the disclosed technology.

FIG. **6** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using a single input step of an embodiment of the disclosed technology.

FIG. **7** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using multiple detection steps of an embodiment of the disclosed technology.

FIG. **8** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using multiple detection steps, modeling steps, and predicting steps of an embodiment of the disclosed technology.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE DISCLOSED TECHNOLOGY

A system for obtaining improved position accuracy with ground penetrating radar includes a PLD capable of detecting objects, such as substrate objects, at at least two points along an extent thereof. Methods for its use include collecting, modeling, and comparing detected radar data with other detected radar data and/or previously input data and/or assumed and/or predicted data.

Embodiments of the disclosed technology will become more clear in view of the following discussion of the figures.

FIG. **1** shows a top plan of elements involved in obtaining improved positional accuracy with ground penetrating radar of an embodiment of the disclosed technology. FIG. **2** shows a front right side elevation view of the elements of FIG. **1** of an embodiment of the disclosed technology. A radar system **10** is equipped with a Locating Determining System **20**. Together (**10** and **20**) they are called the Position Locating Device (PLD). The radar system **10**, in the embodiment shown, is capable of detecting one or more subsurface objects **30** within an area **60**.

In some methods, the PLD (**10** and **20**) is capable of moving autonomously and/or of being moved along a path of travel **40** such that the PLD (**10** and **20**) passes over one or more locations **50** corresponding to one or more subsurface objects **30**. In various embodiments, the PLD (**10** and **20**) performs position location calculations constantly (i.e. at a rate of at least one calculation per second). In other embodiments, the PLD (**10** and **20**) includes a movement-sensitive component, such as an accelerometer and/or gyroscope, and performs position location calculations constantly while movement of the PLD (**10** and **20**) is detected. In further embodiments, the PLD (**10** and **20**) performs position location calculations at a fixed, non-constant rate (such as a rate of one calculation every five seconds).

FIG. **3** shows a flowchart of components of a PLD for obtaining improved positional accuracy with ground penetrating radar of an embodiment of the disclosed technology. In the embodiment shown, the device **10** includes a display unit **21** which is attached to a memory unit **22**. The memory unit **22** is connected to an I/O (input/output) unit **25**, which is in turn connected to a cloud unit **26** and a storage unit **27**. In other embodiments, the I/O unit **25** may be connected to one or the other of the cloud unit **26** and the storage unit **27**.

The memory unit **22** is further connected to a processor unit **23**, which is in turn connected to an antenna unit **24**. The antenna unit **24** may include any system known within the art to be capable of transmitting, and receiving ground-penetrating radar data. The processor unit **23** may be any system capable of interpreting, analyzing, and/or modeling ground-penetrating radar data.

In some embodiments of the disclosed technology, the device **10** further includes an input unit capable of receiving input, entered manually or automatically, including building data, building code data, previously detected and/or predicted radar data, and/or previously built and/or predicted models based on radar data.

Any of the above-described units, apart from the antenna unit **24**, may be connected to the other above-described units in the configuration described above by way of a virtual connection. Any of the above-described units may include multiple internal units, either working redundantly (such that each respective internal unit behaves as an individual unit) or working in a distributed format (such that the overall unit appears to behave as a cohesive whole).

FIG. **4** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using multiple detection steps and multiple retrieval steps of an embodiment of the disclosed technology. In a step **100**, the device **10** detects a first subsurface object **30** at at least two points thereof. The two points may be along and/or adjacent to a path of travel **40** of the device **10**. In a subsequent step **200**, the device **10** retrieves an assumed or determined linear extent of the detected subsurface object **30**. The assumed or determined linear extent, in embodiments, is retrieved by the memory unit **22** of the processor from the cloud unit **26** and/or the storage unit **27** by way of the I/O unit **25**.

In a subsequent step **300**, the device **10** calculates a difference between the detected data and the retrieved data. The detected data compared to the retrieved data may be a modeled and/or an assumed linear extent of the detected subsurface object **30** based on the at least two detected points thereof. In a subsequent step **400**, the device **10** corrects its calculated position based on a difference resulting from the comparison between the detected data and the retrieved data. The pose correction may include calculating and/or recalculating an offset to be applied to position data stored on the device **10**.

In a subsequent set of steps **500**, **600**, **700**, **800** one and/or more of the steps **100**, **200**, **300**, **400** are repeated one and/or more times. In some embodiments, each set of subsequent repeated steps **500**, **600**, **700**, **800** is repeated at a constant rate (such as a rate of one repetition per second). In other embodiments, each set of subsequent repeated steps **500**, **600**, **700**, **800** is repeated at a periodic rate (such as a rate of one repetition per five seconds). In further embodiments, each set of subsequent repeated steps **500**, **600**, **700**, **800** is repeated following a prompt from a source external to the device **10** (such as an input command from a user) or following a prompt internal to the device **10** (such as a detection of movement by a movement-sensitive device such as an accelerometer or a gyroscope).

FIG. **5** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using a single detection step and a single retrieval step of an embodiment of the disclosed technology. In a step **900**, the device **10** detects a first subsurface object **30** at at least two points thereof along a first axis. The two points may be along and/or adjacent to a path of travel **40** of the device **10**. In a step **1000**, the device **10** detects a first subsurface object **30** at at least two points thereof along a second axis. The two points may be along and/or adjacent to a path of travel **40** of the device **10**. The first and second axes may be perpendicular to each other. Each of the first and second axis may be within a plane parallel to a plane containing the path of travel **40** of the device **10**.

In a subsequent step **1100**, the device **10** detects a rotational angle of the first subsurface object **30** relative to the device **10** at least two points thereof. The detected rotational angle, in embodiments, is based on an analysis by the device **10**, such as in the processor unit **23**, of the at least two points detected along the first subsurface object **30** in the first axis and of the at least two points detected along the first subsurface object **30** in the second axis. In a subsequent step **1200**, the device **10** retrieves an assumed or determined linear extent of the detected subsurface object **30** as well as an assumed or determined rotational angle thereof. The assumed or determined linear extent and rotation angle, in embodiments, are retrieved by the memory unit **22** of the processor from the cloud unit **26** and/or the storage unit **27** by way of the I/O unit **25**.

In a subsequent step **1300**, the device **10** calculates a difference between the detected data and the retrieved data. The detected data compared to the retrieved data may be a modeled and/or an assumed linear extent in the first and/or second axes and/or rotational angle of the detected subsurface object **30** based on the at least two detected points thereof in the first axis and/or the at least two detected points thereof in the second axis and the calculated and/or detected rotational angle thereof. In a subsequent step **1400**, the device **10** corrects its calculated position based on a differ-

ence resulting from the comparison between the detected data and the retrieved data. The pose correction may include calculating and/or recalculating an offset to be applied to position data stored on the device **10**.

FIG. **6** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using a single input step of an embodiment of the disclosed technology. In a step **1500**, information is input into the device **10**, such as by way of an input unit into the device **10** itself and/or by way of an input unit into the cloud unit **26** and/or by way of an input unit into the storage unit **27**. In a subsequent step **1600**, the device **10** then performs a pose correction. The correction of step **1600** may be any form/method thereof, including, but not limited to, forms/methods of correction discussed in this specification.

The information/data input in step **1500** may include data regarding any or all of the following: specific arrangements of subsurface objects **30** in one or more specific places, such as buildings; building codes for one or more category of building; radar signatures of differing materials from which subsurface objects **30** may be constructed; previous radar data from previous detections in one or more places, such as buildings; and/or information, such as year of construction and identity of constructor/constructors, regarding one or more places, such as buildings.

In embodiments, the pose correction of step **1600** may include detecting a pattern and/or a discontinuation of a pattern among detected arrangements of previously-detected subsurface objects **30**. The pose correction of step **1600** may further include comparing a set of and/or a set of sets of collected subsurface radar data with a set of building codes input in the step **1500** of inputting, such that one or more building codes may be selected as likely predictors of subsequent sets of subsurface radar data. Following a pose correction of step **1600**, the device **10** may transfer, such as by way of the I/O unit **25**, a set of collected subsurface radar data and/or a set of meta information, such as pose and/or date-time information to one or both of the cloud unit **26** and the storage unit **27**.

FIG. **7** shows a flowchart of a method of use of a PLD for obtaining improved positional accuracy with ground penetrating radar using multiple detection steps of an embodiment of the disclosed technology. In a step **1700**, an estimate of device **10** pose is determined, based on previously collected and analyzed data, including (but not limited to) previously collected and analyzed radar, accelerometer, and gyroscope data. In a subsequent step **1800**, the device **10** detects a set of radar data relating to one or more subsurface objects **30**, such as by way of the antenna unit **24**.

In a subsequent step **1900**, the device **10** creates, such as by way of the processor unit **23**, an inverse model of the collected set of radar data. In various embodiments, the device **10** may create, such as by way of the processor unit **23**, any form of model and/or analysis of the collected set of radar data such that a comparison may subsequently be made using the model and/or analysis. In embodiments, the process of creating an inverse model, or any form of model and/or analysis of the collected data, may be performed externally to the device **10**, such as by a method of sending the collected set of radar data to a processor unit external to the device **10** and subsequently retrieving, from a same or different processor unit external to the device **10**, an inverse model or any form of model and/or analysis of the collected and subsequently sent set of radar data.

In a subsequent step **2000**, the device **10** compares, such as by way of the processor unit **23**, the inverse model of the collected set of subsurface radar data to a known, determined, or assumed set of subsurface radar data. In a subsequent step **2100**, the device **10** calculates, such as by way of the processor unit **10**, a best fit pose between the inverse model obtained in the step **1900** of creating an inverse model and the known, determined, or assumed set of subsurface radar data. The step **2000** of comparison and/or the step **2100** of calculation may furthermore produce a measure of difference between the collected set of subsurface radar data and the known, determined, or assumed set of subsurface radar data.

In embodiments, an additional step exists of the device **10** retrieving a set of known, determined, or assumed subsurface radar data. The known, determined, or assumed subsurface radar data, in embodiments, is retrieved by the memory unit **22** of the processor from the cloud unit **26** and/or the storage unit **27** by way of the I/O unit **25**.

In embodiments, a second additional step exists of the device **10** creating, such as by way of the processor unit **23**, an inverse model of the retrieved set of known, determined, or assumed radar data. The second additional step of creating may be performed in a same or different way as compared to the step **1900** of the device **10** creating an inverse model of the collected set of radar data.

In a subsequent step **2200**, the device **10** maps the calculated best fit pose obtained in the step **2100** of calculating to a likely pose of the device **10**. In some embodiments, this mapping is performed by way of calculating an offset of the estimated device **10** pose of the step **1700** of estimating. In a subsequent step **2300**, the device **10** predicts a pose, such as relative to the device **10**, of an anticipated subsequently-to-be-detected set of subsurface radar data.

FIG. **8** shows a flowchart of a method of use of a PLD for obtaining improved pose accuracy with ground penetrating radar using multiple detection steps, modeling steps, and predicting steps of an embodiment of the disclosed technology. In a step **2400**, an estimate of device **10** pose is determined, based on previously collected and analyzed data, including (but not limited to) previously collected and analyzed radar, accelerometer, and gyroscope data. In a subsequent step **2500**, the device **10** detects a set of radar data relating to one or more subsurface objects **30**, such as by way of the antenna unit **24**.

In a subsequent step **2600**, the device **10** creates, such as by way of the processor unit **23**, an inverse model of the collected set of radar data. In various embodiments, the device **10** may create, such as by way of the processor unit **23**, any form of model and/or analysis of the collected set of radar data such that a comparison may subsequently be made using the model and/or analysis. In embodiments, the process of creating an inverse model, or any form of model and/or analysis of the collected data, may be performed externally to the device **10**, such as by a method of sending the collected set of radar data to a processor unit external to the device **10** and subsequently retrieving, from a same or different processor unit external to the device **10**, an inverse model or any form of model and/or analysis of the collected and subsequently sent set of radar data.

In a subsequent step **2700**, the device **10** compares, such as by way of the processor unit **23**, the inverse model of the collected set of subsurface radar data to a known, determined, or assumed set of subsurface radar data. In a subsequent step **2800**, the device **10** calculates, such as by way of the processor unit **10**, a best fit pose between the inverse model obtained in the step **2600** of creating an inverse model and the known, determined, or assumed set of subsurface radar data. The step **2700** of comparison and/or the step **2800** of calculation may furthermore produce a measure of dif-

ference between the collected set of subsurface radar data and the known, determined, or assumed set of subsurface radar data.

In a subsequent step **2900**, the device **10** maps the calculated best fit pose obtained in the step **2100** of calculating to a likely pose of the device **10**. In some embodiments, this mapping is performed by way of calculating an offset of the estimated device **10** pose of the step **2400** of estimating. In a subsequent step **3000**, the device **10** predicts a pose, such as relative to the device **10**, of an anticipated subsequently-to-be-detected set of subsurface radar data.

In a subsequent set of steps **3100**, **3200**, **3300**, **3400**, and **3500**, the device **10** repeats the series of steps **2500**, **2600**, **2700**, **2800**, and **2900** using a set of subsequently detected subsurface radar data. In a subsequent step **3600**, the device **10** compares the calculated likely device pose obtained in the step **3500** of mapping with the predicted pose of anticipated subsequently-detected set of subsurface radar data obtained in the step **3000** of predicting. In a subsequent step **3700**, the device **10** recalculates the likely pose of the device **10** based on the comparison obtained in the step **3600** of comparing. The pose of device **10** may be further corrected based on the comparison obtained in the step **3600** of comparing, such as by changing an offset value to be applied to an estimate subsequently made regarding a pose of the device **10**.

In embodiments, following the device **10** predicting a pose, such as relative to the device **10**, of an anticipated subsequently-to-be-detected set of subsurface radar data, the device **10** performs one or more subsequent comparisons between only the predicted pose of the anticipated subsequently-to-be-detected set of subsurface radar data and one or more sets of subsequently detected subsurface radar data.

For purposes of this disclosure, the term "substantially" is defined as "at least 95% of" the term which it modifies.

Any device or aspect of the technology can "comprise" or "consist of" the item it modifies, whether explicitly written as such or otherwise.

When the term "or" is used, it creates a group which has within either term being connected by the conjunction as well as both terms being connected by the conjunction.

While the disclosed technology has been disclosed with specific reference to the above embodiments, a person having ordinary skill in the art will recognize that changes can be made in form and detail without departing from the spirit and the scope of the disclosed technology. The described embodiments are to be considered in all respects only as illustrative and not restrictive. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope. Combinations of any of the methods and apparatuses described hereinabove are also contemplated and within the scope of the invention.

The invention claimed is:

1. A position locating device comprising:

a ground penetrating radar transceiver; and

a location determining system;

wherein said device is configured such that a first detection, by way of said ground penetrating radar transceiver, of a first subsurface object at, at least, two different points, said two different points extending in a direction other than a path of travel of said position locating device during said first detection, is used to correct a pose of said position locating device relative to said first subsurface object based on an assumed or determined linear extent of said subsurface object.

2. The position locating device of claim **1**, wherein said direction of said extent of said at least two different points is perpendicular to said path of travel of said position locating device during said first detection.

3. The position locating device of claim **1**, wherein a longest extent of said first subsurface object is perpendicular relative to said path of travel of said position locating device.

4. The position locating device of claim **1**, wherein a longest extent of said first subsurface object is at a non-right angle relative to said path of travel of said position locating device.

5. The position locating device of claim **1**, wherein said device is further configured such that following said first detection of said first subsurface object and said first pose correction, a subsequent second detection, by way of said ground penetrating radar transceiver, of a second subsurface object at, at least, two different points, said two different points extending in a direction other than a path of travel of said position locating device during said second detection, is used to further correct a pose of said position locating device relative to said first subsurface object and said second subsurface object based on an assumed or determined extent of said first subsurface object and said second subsurface object.

6. The position locating device of claim **5**, wherein a longest extent of one of said first and said second subsurface objects is perpendicular relative to said path of travel of said position locating device and a longest extent of an other of said first and said second subsurface objects is at a non-right angle relative to said path of travel of said position locating device, at each of a time when said pose correction occurs as a result of travel of said position locating device over a respective said first subsurface object and a time when said pose correction occurs as a result of travel of said position locating device over a respective said second subsurface object.

7. The position locating device of claim **1**, wherein said pose correction comprises:

a detection of said subsurface object in a first axis; and

a detection of said subsurface object in a second axis; and

a determination of a location of said position locating device relative to each of said first axis and said second axis;

wherein said first axis is perpendicular to said second axis; and

wherein said subsurface object is known, determined, and/or assumed to be linear;

wherein each of said first axis and said second axis is located along a longest linear extent and/or a shortest linear extent and/or a diagonal linear extent of said subsurface object;

wherein said determined location is used to detect a pose of said position locating device independently and/or to confirm and/or specify a predetermined pose thereof.

8. The position locating device of claim **7**, further comprising at least one antenna;

wherein said pose correction further comprises a detection of a rotational angle of said position locating device relative to said subsurface object by way of said antenna.

9. The position locating device of claim **1**, further comprising an input device, wherein said assumed linear extent of said subsurface object is based on known building code information inputted into said input device.

10. A method of using the position locating device of claim **1**, comprising steps of:

detecting, in a first detection, by way of said ground penetrating radar transceiver, a first subsurface object at, at least, two different points, said two different

points extending in a direction other than a path of travel of said position locating device during said first detection; and

correcting a pose of said position locating device relative to said first subsurface object using said at least two different points, based on an assumed or determined linear extent of said subsurface object.

11. The method of claim **10**, wherein during said step of first detecting, said direction of said extent of said at least two different points is perpendicular to said path of travel of said position locating device.

12. The method of claim **10**, wherein during said step of first detecting, a longest extent of said first subsurface object is perpendicular relative to said path of travel of said position locating device.

13. The method of claim **10**, wherein during said step of first detecting, a longest extent of said first subsurface object is at a non-right angle relative to said path of travel of said position locating device.

14. The method of claim **10**, further comprising the steps of:

further detecting, in a second detecting, following said steps of said first detecting and correcting, a second subsurface object at, at least, two different points, said two different points extending in a direction other than a path of travel of said position locating device during said first step of detecting and/or said second step of detecting; and

further correcting a pose of said position locating device relative to said first subsurface object and said second subsurface object, using said at least two different points of said step of second detecting, based on an assumed or determined linear extent of said first subsurface object and said second subsurface object.

15. The method of claim **14**, wherein during said step of second detecting, a longest extent of one of said first and said second subsurface objects is perpendicular relative to said path of travel of said position locating device and a longest extent of an other of said first and said second subsurface objects is at a non-right angle relative to said path of travel of said position locating device each of, at each of a time of said first detection and pose correction and a time of said second detection and said further correction.

16. The method of claim **10**, wherein said pose correction comprises steps of:

detecting said subsurface object in a first axis;

detecting said subsurface object in a second axis; and

determining a location of said position locating device relative to each of said first axis and said second axis;

wherein said first axis is perpendicular to said second axis; and

wherein said subsurface object is known, determined, and/or assumed to be linear;

wherein each of said first axis and said second axis is located along a longest linear extent and/or a shortest linear extent and/or a diagonal linear extent of said subsurface object;

wherein said determined location is used to detect a pose of said position locating device independently and/or to confirm and/or specify a predetermined pose thereof.

17. The method of claim **16**, wherein said position locating device further comprises at least one antenna;

wherein said pose correction further comprises a step of detecting a rotational angle of said position locating device relative to said subsurface object by way of said antenna.

18. The method of claim **10**, wherein said position locating device further comprising an input device;

wherein said method further comprises a step of inputting known building code information into said input device;

wherein said known building code information comprises at least said assumed linear extent of said subsurface object.

19. A method of correcting for pose errors of a position locating device, comprising the following steps:

determining a substantial pose error of a position locating device;

detecting, in a first step of detection, by way of a ground penetrating radar transceiver of said position locating device, at least one set of subsurface radar data;

creating, using said at least one set of subsurface radar data, an inverse model of reflections and/or diffractions included within said at least one set of subsurface radar data;

comparing said inverse model with known, determined, and/or assumed subsurface data;

calculating a best-fit pose between said inverse model and said known, determined, and/or assumed subsurface data;

mapping said best-fit pose to a most likely pose of said position locating device; and

predicting at least one most likely pose of at least one anticipated subsequent set of subsurface radar data to be detected, in at least a second step of detection, by way of said ground penetrating radar transceiver of said position locating device.

20. The method of claim **19**, further comprising the following steps:

detecting, in a second step of detection, at least one subsequent set of subsurface radar data;

creating, using said at least one subsequent set of subsurface radar data, an inverse model of reflections and/or diffractions included within said at least one subsequent set of subsurface radar data;

comparing said inverse model with known, determined, and/or assumed subsurface data;

calculating a best-fit pose between said inverse model and said known, determined, and/or assumed subsurface data;

mapping said best-fit pose to a most likely pose of said position locating device;

comparing said determined most likely pose of said position locating device based on said at least one subsequent set of subsurface radar data with said previously-predicted most likely pose of said position locating device;

determining, based on said comparison, a most likely pose of said position locating device; and

predicting, based on said determined most likely pose of said position locating device, at least one most likely pose of at least one additional anticipated subsequent set of subsurface radar data to be detected, in at least a third detection, by way of said ground penetrating radar transceiver of said position locating device.

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