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(71) Applicant: I.D.S. - INGEGNERIA DEI SISTEMI - S.P.A. [ΓΓ/IT]; Via Enrica Calabresi 24, 1-56121 Pisa (IT).

(72) Inventors: MANACORDA, Guido; Via G.B.Funaioli, 7, 1-56100 Pisa (IT). **MINIATI, Mario;** Via Adolfo Tommasi 18/c, 1-57100 Pisa (ΓΓ).

(74) Agent: CELESTINO, Marco; Viale Giovanni Pisano, 31, 1-56123 Pisa (IT).

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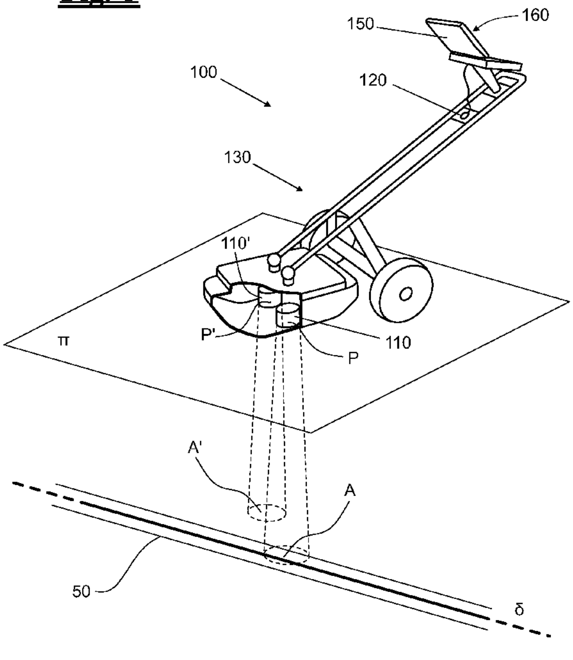
Fig. 1



(57) Abstract: A method for defining a lay direction δ of at least one elongated buried object (50), by means of GPR technique (Ground Penetrating Radar), comprises the steps of moving a first GPR sensor (110) along a first trajectory s consisting of a plurality of points P, and moving a second GPR sensor (110'), integral to the first GPR sensor (110), along a second trajectory s' consisting of a plurality of points P' and parallel to the first trajectory s. The method also comprises the steps of detecting a first and a second plurality of presence signals concerning possible buried objects by the first GPR sensor (110) and the second GPR sensor (120), acquisition of a first and a second set of spatial coordinates for each point P and P' at which a presence signal is detected, and receiving by a control unit (150) the presence signals and the set of spatial coordinates. The method provides then a step of computing the data concerning the presence of possible buried elongated objects (50) and the set of spatial coordinates, in order to determine, among all points P and P' at which a presence signal has been detected, points **Pi** and **Pi'** at which the probability of presence of an elongated buried object (50) is higher. Then, a step of determining, at the end of said computing step, the lay direction δ of at least one elongated buried object (50) is carried out responsive to the set of spatial coordinates corresponding to points **Pi** and **Pi'**.

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TITLE

DEVICE AND METHOD FOR DETECTING POSITION AND ORIENTATION OF UNDERGROUND ELONGATED BODIES

DESCRIPTION

Field of the invention

The present invention relates to a method for detecting, by means of GPR (Ground Penetrating Radar), underground ducts and for computing their lay direction.

Furthermore, the invention relates to an apparatus that carries out this method.

Description of the prior art

Inspecting devices are known that provide radio frequency energy for searching, by radar techniques, objects present in the underground, in walls of buildings, or in other hidden sites, with various applications in the fields of building engineering, geology, archaeology. These devices have the merit not to affect the physical, chemical and mechanical features of the structures and of the material that surround them.

In such devices, known as ground penetrating radars or with the acronyms GPR (Ground Penetrating Radar) or SPR (Surface Penetrating Radar), at least one antenna is provided for receiving/transmitting a radiofrequency (GPR sensor) and a remote control unit comprising a PC and an interface board with the or each antenna are also provided. The operation of these devices is typical of radars emitting an RF signal and analysing a return signal reflected by the objects hit by the emitted signal (echo). The GPR sensor is displaced on the surface of the target material, and, once started the transmission, the received return signals, suitably filtered, are generally displayed in the form of two-dimensional images, representing the amplitude versus time (ordinate) and of the space (abscissa) with respective coding colours.

The principles of operation of Ground Penetrating Radars are described for example in *"Surface penetrating radar 2nd edition"* by D. J. Daniels "The Institution of Electric Engineers, Stevenage (UK), 2004", or *"IDS Radar Products For Utilities Mapping And Ground Classification"* by Guido Manacorda "Proceedings of 20th International NO-DIG Conference and Exhibition Copenhagen Denmark, May 28-31, 2002" available also in www.idscorporation.com.

Normally, the ground penetrating radars of the prior art, used in defining and mapping underground ducts and cable-ducts, are arranged for scanning along directions perpendicular to each other, i.e. defining a grid of measurement points. Such steps are long and difficult, but are necessary for determining the lay direction of buried objects whose direction is not known or it cannot be evaluated a priori. A ground penetrating radar is in fact capable of measuring precisely only ducts and underground cable-ducts with a lay direction perpendicular to the scanning direction. In this case, in fact, the position and the depth of the target are obtained by simply reading in the radar image the coordinates of a hyperbolic shape reflected by the duct or by the cable-duct.

In order to overcome this problem, some of the known ground penetrating radars use an array of GPR sensors, in order to speed up the inspection owing to the decrease of the number of scanning travels to carry out.

However, also in this case, the step of locating the lay direction of the buried objects is not immediate, but it is necessary to carry out many scanning travels to follow all the possible lay directions of the buried object.

In DE10018031A1 , for example, a ground penetrating radar is described that uses two adjacent GPR antennas working alternately to each other. The two antennas are at a distance from each other along a line perpendicular to the travel direction of the ground penetrating radar. Furthermore, they are at an angle a for partially overlapping the trajectories of the two signals coming from the antennas, in order to follow the lay direction of the buried objects by comparing the two generated radar images with the data provided by the two antennas .

According to DE10018031A1 , in fact, by moving the antennas along the lay direction of the duct or cable-duct, the signal from it reflected returns to the ground penetrating radar with a delay substantially fixed and responsive to the distance between the antennas and the duct. Therefore, the trajectory is found moving the apparatus until the response time of the signals produced by the two antennas is minimum, corresponding to a position of the radar aligned vertically to the duct.

The device described in DE10018031A1 has a plurality of technical problems. Firstly, for detecting a duct it is necessary that the two antennas are at an angle a in such a way that the transmitted signals overlap when they meet each other at the depth of the duct. So, according to DE10018031A1 , it is essential to know a priori the depth of the sought ducts and cable-ducts, and this often is not possible. Such aspect is already disadvantageous in case of a large duct laid at a fixed depth, but it is almost prohibitive when the duct changes the depth along its path.

Furthermore, the need of overlapping the signals at the duct prevents detecting ducts too close to the ground surface, since it would be necessary a too high angle a of inclination of the antennas.

Another drawback of the device presented in DE10018031A1 relates to the angle a that, as disclosed, changes between 5° and 16°. The angle at which the signals are transmitted with respect to a vertical direction causes a worsening of the amplitude of the received signal, when the duct is not struck by the main beam of the antenna but by a secondary lobe.

Finally, an unreliable detection of the direction of the pipes is caused by an impossibility of following exactly the direction of the duct during the travel of the ground penetrating radar. In fact, if the antennas detect a same signal, the radar is positioned symmetric with respect to the duct. If this symmetry is kept precisely, then the radar travel is directed parallel to the duct and aligned vertically to the same. In practice, however, it is not possible to keep such symmetry, since its precision is almost impossible to check. In particular, using antennas with a large beam of waves, as normally used in ground penetrating radars, the method would cause an unreliability in detecting the depth of the duct which is about half the distance between the antennas.

Summary of the invention

It is therefore a feature of the present invention to solve the above described technical problems present in the prior art.

It is also a feature of the present invention to provide a method that, by means of GPR technique (Ground Penetrating Radar) allows defining the lay direction of an elongated buried object carrying out a single scanning step.

It is also a feature of the present invention to provide a method for defining this lay direction in real time during the scanning.

It is a further feature of the present invention to provide a method for tracking an elongated buried object along all its lay direction, in order to determine possible changes of the lay direction.

It is still a feature of the present invention to provide a method for displaying said lay direction on a map referred to a global reference system and/or a local reference system.

It is also a feature of the present invention to provide a method for defining the duct lay direction in an automatic way and without the need for an expert staff.

It is a further feature of the present invention to provide an apparatus that carries out such method.

These and other objects are achieved by a method for defining a lay direction δ of at least one elongated buried object by means of GPR technique (Ground Penetrating Radar) comprising the steps of:

- moving a first GPR sensor along a first trajectory s consisting of a plurality of points P, said first trajectory s having origin at a predetermined point P_0 and having as tangent line, at each point P of said plurality, a predetermined direction y;

- moving a second GPR sensor, integrally to the first GPR sensor, so that the second GPR sensor travels along a second trajectory s' consisting of a plurality of points P', said second trajectory s' having origin at a predetermined point P_0' and being parallel to the first trajectory s, said second trajectory s' having as tangent line, at each point P' of said plurality, a predetermined direction y', said second GPR sensor spatially arranged in such a way that a connecting line between the first GPR sensor and the second GPR sensor defines a predetermined direction ε not parallel to the directions y and y';

- detecting a first plurality of presence signals by the first GPR sensor, each presence signal of said first plurality being detected at least at one point P of the first trajectory s, said first plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object at a first area (A) defined in a neighbourhood of a projection of point P on the elongated buried object;

– determining a first set of spatial coordinates for each point P of the trajectory s in which a presence signal of said first plurality is detected;

– detecting a second plurality of presence signals by the second GPR sensor, each presence signal of said second plurality being detected at least at one point P' of said second trajectory s', said second plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object along a substantially vertical direction passing through point P';

– determining a second set of spatial coordinates for each point P' of the trajectory s' in which a presence signal of said second plurality is detected;

– sending to a control unit the first and of the second plurality of presence signals and each first and second set of spatial coordinates;

– computing a presence record concerning the presence of possible buried elongated objects and of each first and second set of spatial coordinates, by:

determining, among all points P and P' at which a presence signal has been detected, points P_1 and P_1' at which the probability of presence of an elongated buried object is higher; and

comparing said sets of spatial coordinates corresponding to points P_1 and Pi' with each other;

- determining, at the end of said computing step, the lay direction δ of at least one elongated buried object responsive to the set of spatial coordinates corresponding to points P_1 and P_1'.

The method according to the invention allows then defining the lay direction of an elongated buried object with a single scanning, by simply determining the spatial coordinates of points P_1 and P_1'.

In particular, the computing step can be carried out through a program means resident in the control unit, in such a way that the computing step is automatic and the step of locating the lay direction δ is carried out in real time during the scanning step.

Advantageously, the computing step comprises a step of computing an angle a set between a direction x orthogonal to the directions y and y' and an expected lay direction δ_ι of the elongated object, said expected lay direction δ_ι computed by comparison of a set of spatial coordinates of points P_1 and P_i' in which data have been detected relative to the presence of a same elongated buried object.

In particular, the method further comprises the steps of:

- positioning the apparatus in such a way that direction y is orthogonal to the expected lay direction δ_1;
- iterating the steps of:
  detecting the first plurality of presence signals;
  determining the first set of spatial coordinates of each point P;
  detecting the second plurality of presence signals;
  determining the second set of spatial coordinates of each point P';
  receiving the first and the second plurality of presence signals and the first and the second set of spatial coordinates;
  computing angle a;

  said step of iterating repeated until angle a is zero;
- identifying, when angle α is zero, of the expected lay direction δ_ι as the actual lay

direction δ.

Such iterative process reduces effectively and with low computational burden possible any measurement errors occurred during the first detecting step of presence signals and/or the first step of determining the set of spatial coordinates.

Advantageously, in case the computing step is made through program means, a step is also provided of filtering and amplifying the first and the second plurality of presence signals, to allow a quicker and more precise identification of points P_i and P_i'.

Advantageously, when the lay direction δ in an inspected zone has been identified, the method according to the invention provides a moving step where the apparatus is caused to translate laterally in a immediately next subsequent zone in order to check that this lay direction δ is the same as the previous zone or, alternatively, in order to determine the lay direction δ in the subsequent zone. Such step can be repeated many times, in order to follow the buried objects along all its lay direction.

In particular, in this moving step the apparatus in the inspected zone, direction y is kept orthogonal to the direction δ in the previous zone, in order to assist the comparison with the previous zone and determine easily the direction δ of the buried object in the inspected zone. The maintenance of the orthogonality between direction y and the lay direction δ can be simplified, for example, by a navigation device.

In particular, the set of spatial coordinates of each point P is referred to a reference system selected from the group consisting of:

- a relative reference system having origin at said predetermined point P_0;
- a global reference system;
- or a combination thereof;

In particular, the set of spatial coordinates of each point P' is referred to a reference system selected from the group consisting of:

- a relative reference system having origin at said predetermined point P_0';
- a global reference system;
- or a combination thereof.

According to another aspect of the invention, an apparatus for defining a lay direction δ of at least one elongated buried object comprises a first GPR sensor configured to measure a first plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object;

whose characteristic is that it further comprises:

- a second GPR sensor arranged integrally to the first GPR sensor in such a way that a connecting line between the first GPR sensor and the second GPR sensor defines a predetermined direction ε not parallel to the directions y and y', said second GPR sensor (110') configured to measure a second plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object;
- at least one position sensor arranged to detect a first set of spatial coordinates for each point P of the trajectory s in which a presence signal of said first plurality is detected, said or each position sensor being also arranged to detect a second set of spatial coordinates for each point P' of the trajectory s' in which a presence signal of said second plurality is detected;
- A control unit arranged for receiving the first and the second plurality of presence signals by the first and by the second GPR sensor and each first and second set of spatial coordinates from said or each position sensor.

Advantageously, a program means is also comprised resident in the control unit and configured to analyse each first and second set of spatial coordinates and the data concerning the presence of possible buried elongated objects, said control unit being also configured for:

determining, among all points P and P' at which a presence signal has been detected, points Pi and P_1' at which the probability is higher of presence of said or each elongated buried object; and

comparing said sets of spatial coordinates corresponding to points Pi and Pi' with each other;

- determining, at the end of the control step, the lay direction δ of at least one elongated buried object responsive to the set of spatial coordinates corresponding to points Pi and Pi' .

This way, the step of locating the lay direction δ is done in an automatic way and in real time, needing a single scanning.

In particular, the program means is also arranged to filter and amplify the presence signals, to allow a quicker and more precise identification of points Pi and Pi'

Advantageously, a navigation device is also provided, operatively connected to the control unit, and arranged to guide the first GPR sensor and the second GPR sensor in such a way that the directions y and y' turn out parallel or orthogonal to the lay direction δ of said or each elongated object. This way, the apparatus can determine easily the whole lay direction of said or each elongated object.

In particular, the navigation device is selected from the group consisting of:

- an analog compass;
- a digital compass;
- an accelerometer ;
- a GPS device;
- a total station;
- a gyroscope;
- an inertial station;
- a combination thereof.

Advantageously, the navigation device is configured to guide the first GPR sensor and the second GPR sensor orthogonally to an expected lay direction δ_1 and the program means is configured to determine, at the end of the computing step carried out by said program means, a lay direction δ, and to check that it coincides with the expected lay direction δ_1.

This way, it is possible to set an iterative process for improving the precision for defining the lay direction δ, reducing effectively and quickly any measurement errors occurred during the first detecting step of presence signals and/or the first step of determining the set of spatial coordinates.

In particular, said or each position sensor is selected from the group consisting of:

- a rotational encoder;
- a metric wheel;
- a GPS device;
- a total station;
- a gyroscope;
- a GPS device;
- an inertial station;
- a measuring device of the travelled distance;
- a combination thereof.

In particular, the first and/or the second GPR sensor are selected from the group consisting of:

- an element type antenna (i.e. monopole, dipole, bow-tie, etc.);
- a "frequency independent" antenna (i.e. Logperiodic, spiral-shaped, Vivaldi, etc.);
- a horn antenna;
- an ultra-wide band non dispersive antenna (i.e. travelling wave antenna, travelling wave TEM horn, Impulse Radiating Antenna, rod antenna, etc.)
- a combination thereof.

Advantageously, a movable support is also provided arranged to support the first GPR sensor and the second GPR sensor to assist that said GPR sensors are moved integrally to each other.

In particular, the movable support is also arranged to support the other components of the apparatus.

Brief description of the drawings

Further characteristic and/or advantages of the invention will be made clearer with the following description of an embodiment thereof, exemplifying but not limitative, with reference to the attached drawings in which:

- Fig. 1 shows a possible exemplary embodiment of an apparatus, according to the invention, for defining a lay direction δ of at least one elongated buried object;
- Fig. 2 shows a step of moving the apparatus on a target surface;
- In Fig. 3 a step is shown of locating a first point P_1 at which there is a high probability of presence of a buried object;
- In Fig. 4 a step is shown of locating a second point P_i' at which there is a high probability of presence of a buried object, and subsequently defining an expected lay direction δ_1;

- In Fig. 5 a step is shown of further positioning apparatus 100 for testing the expected lay direction δ_1 of the buried object;
- In Fig. 6 a moving step is shown where the apparatus is caused to translate laterally in a immediately next subsequent zone to follow the lay direction of the buried object;
- In Fig. 7A examples are shown of measured presence signals, in case of $\boldsymbol{a} \neq 0$;
- In Fig. 7B examples are shown of measured-presence signals, in case of $a = 0$;
- In Fig. 8 a flow-sheet is shown which outlines various steps of the method for defining the lay direction δ of buried elongated objects, according to the invention.

<u>Description of a preferred exemplary embodiment</u>

With reference to Fig. 1, a possible exemplary embodiment of an apparatus 100, according to the invention, for defining a lay direction δ of at least one elongated buried object 50 comprises a first and a second GPR sensor, 110 and 110', mounted to a movable support 130.

GPR sensors 110 and 110' allow to measure the presence of possible buried elongated objects by sending underground presence signals consisting of short high frequency electromagnetic pulses and then receiving back such signals.

Movable support 130, to which GPR sensors 110 and 110' are integral, assists moving apparatus 100 throughout a target area, and at the same time makes the GPR sensors integral to each other, so that they follow parallel trajectories during the step of detecting the signals.

In particular, assuming a plane n as the plane on which substantially the target area lays, and assuming the positions of GPR sensors 110 and 110' in this plane n respectively as points P and P', GPR sensors 110 and 110' can measure the presence of possible buried elongated objects, respectively at a first area A and of a second area A'. Such areas A and A' are defined, respectively, as a neighbourhood of the projections of points P and P' on elongated buried object 50, and are spatially different from each other. To movable support 130, in this exemplary embodiment, a control unit 150, in particular a computer, and a position sensor 120 are also connected.

To control unit 150 a navigation device 160 can be also connected, which is adapted, for example, to display a lay direction δ so that a user can follow the buried object along all its lay direction.

In figures 2,3,4,5,6 the successive steps of the method according to the invention are diagrammatically shown, for defining a lay direction δ of at least one elongated buried object 50.

With reference to Fig. 2, when apparatus 100 is moved on a target surface substantially parallel to plane n, the two GPR sensors 110 and 110' trace on this plane n two parallel trajectories s and s', consisting of two pluralities of points P and P' and have origin at points Po and P_0'. Furthermore, the two trajectories s and s' have as tangent lines, at each point, directions y and y'. Such directions y and y' are in turn parallel to each other, being the tangential lines to two trajectories parallel to each other, and are also parallel to the conveying direction all apparatus 100. The direction of movement is indicated by an arrow, located underneath apparatus 100.

Two GPR sensors 110 and 110' are integral to each other and located at a fixed distance d. A line that connects the two GPR sensors 110 and 110' has a predetermined direction ε, which forms, in each position of apparatus 100, an angle β not zero with direction y. The distance d has projection hi on direction y and a projection D on a direction x orthogonal to direction y and arranged also in plane n.

Simple trigonometric considerations allow to write the following relations:

$$h_i = d*\cos(\beta)$$

$$D = d*\sin(\beta)$$

When moving apparatus 100 on the target surface, GPR sensors 110 and 110' detect continuatively presence signals that reproduce data relating to the presence of possible buried elongated objects. At the same time, position sensor 120 acquires a set of coordinates in plane n for each point P or P′ in which a presence signal by GPR sensors 110 and 110' is detected. Each set of coordinates can be referred to a reference system having origin at P_o or, alternatively to a global reference system. In the latter case, the position sensor could be, for example, a GPS sensor (Global Positioning System) based on a system of positioning satellites.

The acquired set of coordinates, along with the presence signals, are transmitted, in particular in real time, to control unit 150, which makes it possible a control by a user and/or by means of a software resident in the same control unit 150.

Owing to the acquisition of coordinates of the positions covered in turn by the two GPR sensors 110 and 110', the program means and/or the user are capable of determining the two trajectories s and s' travelled by the GPR sensors same, and then also the directions tangential to y and y' at each point.

In Fig. 3 the instant is shown when one of the two GPR sensors 110 and 110' reveals the presence of a buried object .

Specifically, when control unit 150 receives the presence signals detected by first GPR sensor 110 at point P_1 and at adjacent points, the program means and/or the user compute such signals and detect point P_1 as the point at which there is a high probability of presence of a buried object. The coordinates of point Pi in plane n have already been obtained by. the actual position sensor 120, whereas the coordinate that provides the depth of the buried object at point P_1 is evaluated by the presence signal. It is therefore univocally determined spatially a first point of the lay direction of the elongated buried object.

In Fig. 4 the moment is shown where the step of controlling the presence signals measured by the second sensor 110' allows locating point P_1' as point at which there is a high probability of presence of a buried object. Such step of processing the presence signals allows to determine both the depth of such object, if the buried object detected at point Pi' is the same detected at point Pi.

In case the object detected is the same, the expected lay direction δι of elongated buried object 50 can be determined, since for two points P_1 and Pi' a single straight line can pass. In particular, the expected lay direction δ_1 is defined by computing an angle a between the above described direction δ_1 and a direction x, orthogonal to the travel direction.

As it is apparent, except from the case in which direction δι is not exactly parallel to a connecting line between the sensors 110 and 110', the step of locating points P_1 and P_1' is carried out temporally different steps.

In simplified case of Fig. 4, where the conveying direction of apparatus 100 has been kept fixed in the short time between the steps of locating first point Pi and of second point Pi', the expected lay direction δι is evaluated simply by determining the projection h_2 on y of segment PχPι', i.e. by determining the distance travelled by apparatus 100 in said time.

In this case, in fact, angle a is evaluated, by means of simple trigonometric considerations, by the following equation:

$$\alpha = \tan^{-1}\left(\frac{\frac{d^* \cos\beta + h_2}{d} - \cos\beta}{\sin\beta}\right)$$

wherein β and d are known, and h_2 is the only variable value.

In Fig. 5 a step is shown of further positioning apparatus 100, for testing the expected lay direction δι of elongated buried object 50.

In particular, once an expected lay direction δι of the buried object 50 has been defined, apparatus 100 is positioned again in such a way that direction y is orthogonal to direction δι. This can be made, in particular, by a navigation device 160, for example connected to control unit 150 (see Fig. 1).

The apparatus is then caused to travel along new direction y repeating the steps of detecting the presence signals, computing the coordinates and computing a presence record, up to calculating new a between the new direction x and a new expected lay direction δι.

If this angle a is zero, then the new expected lay direction δ_1 is confirmed as coincident with the expected lay direction δι calculated above and then assumed as the actual lay direction δ, which is defined with respect to the reference system chosen above.

If instead angle a is not zero, and this can occur for example in case of measurement errors that result during the first estimation of δ_1, then a further positioning and verification steps are carried out, giving rise substantially to an iterative process that ends when angle a calculated is eventually zero.

With reference to Fig. 6, when the lay direction δ in the inspected zone has been defined, the method according to the invention provides a moving step where apparatus 100 is caused to translate laterally in a immediately next subsequent zone in order to check that this lay direction δ is the same as the previous zone or, alternatively, in order to determine the lay direction δ in the inspected zone. Such step can be repeated many times, in order to follow the buried object 50 along all its lay direction.

In particular, while moving apparatus 100 in the inspected zone, direction y is kept orthogonal to the direction δ in the previous zone, in order to assist the comparison with the previous zone and determine easily the direction δ of the buried object 50 in the inspected zone.

In a possible exemplary embodiment, the lay direction δ can be displayed on a screen of the navigation device 160 (see Fig. 1), for example on a map oriented with respect to the conveying direction of apparatus 100. This way, a user can direct the movement of apparatus 100 and at the same time can display on the screen the lay direction defined up to that moment. Even in Figs. 2 to 6, both always shown the movable support 130, it is not necessary for the purpose of the operation of the present invention, since GPR sensors 110 and 110' can also be moved by means of other devices and/or manually by a user, without with this affecting the effect technical as claimed .

With reference to Figs. 7A and 7B, the presence signals detected by GPR sensors 110 and 110' can be displayed, for example, as branches of a hyperbole whose vertices correspond to the positions of the points, in particular P_1 and Pi' , at which there is a high probability of presence of an elongated buried object.

In particular, Fig. 7A shows the displays 10 and 10' of the measured presence signals in a simplified case, like that of Fig. 4, where the conveying direction of apparatus 100 has been kept fixed, and parallel to direction y, in the time between the step of locating first point P_1 and of second point Pi' . The travel direction of moving apparatus 100 when detecting the presence signals is indicated by the arrow. Like Fig. 4, by projecting on y segment P_1Pi' the quantity h_2 is obtained, which is necessary to calculate angle a that defines the expected lay direction δ_1 of elongated buried object 50.

Fig. 7B shows instead the displays 20 and 20' of the measured presence signals during a verification step, like that shown in Fig. 5, where apparatus 100 is moved along a direction y perpendicular to the expected lay direction δ_1.

In particular, the case of Fig. 7B shows an alignment of the vertices of the two branches of hyperbole along the expected lay direction δ_1. Such alignment causes zeroing the projection h_2 and therefore of angle a, allowing the verification whether the expected lay direction δ_1 coincides actually with the actual lay direction δ of the elongated buried object.

Both the step of locating the vertices of the branches of hyperbole, and therefore of points Pi and Pi', and the correlation between two presence signals in order to assess whether they belong to a same buried object, are operations that can be carried out visually by a user, starting from the displays as shown in Figs. 7A and *IB.*

Alternatively, for an automatization of the control step, a program means can be further provided in control unit 150. In this case, the step of determining the vertices can be done using an algorithm for recognizing the image that, starting from the above described displays, builds vectorial curves of which is possible, for example, to determine the maximum and/or minimum points .

Furthermore, the program means can carry out also a correlation between two presence signals by means, for example, of a pattern recognition filter and/or a image processing filter.

More in general, when the step of computing the presence signals is made through the program means, a step can also be provided of filtering and/or an amplifying such signals, for assisting the recognition and the correlation of the displayed images.

In Fig. 8 a flow-sheet is shown which outlines various steps of the method for defining the lay direction δ of buried elongated objects, according to the invention.

In particular, a step is provided of moving apparatus 100 on a target surface (201), during which GPR sensors 110 and 110' trace two trajectories s and s', thus detecting continuatively presence signals concerning the presence of possible buried objects (202). At the same time a position sensor 120 acquires the spatial coordinates, with respect to a absolute or relative reference system, of each point of trajectories s and s' at which a presence signal has been received (203).

The presence signals and the spatial coordinates are transmitted to a control unit 150, so that they can be computed by a user and/or by means of a software resident in the control unit same. The computing step allows to define a first point P_i at which it is very probable the presence of a buried object 50 (204), and then to define a second point P_i' at which it is very probable the presence of the same buried object 50 (205).

By computing the line that passes through points P_i and P_i' it is therefore possible to determine an expected lay direction δ_ι of said buried object 50 (206), and then to calculate angle a between the direction x, orthogonal to the conveying direction of apparatus 100, and the above described direction δ_ι (207).

Typically, angle a is not zero (207'), being casual the trajectory chosen when moving apparatus 100.

In this case, therefore, apparatus 100 is positioned again so that direction y, tangential to the trajectory of the apparatus, is perpendicular to the expected lay direction δ_ι as previously defined. Such positioning movement can be made, for example, by means of a navigation device 160.

All the steps previously described (201-207), until angle a is zero (207'') are then repeated. When angle a is zero, the last expected lay direction δ_1 as calculated is confirmed as the actual lay direction δ (208).

At this point, apparatus 100 is caused to translate in a zone next to that previously inspected, maintaining direction y perpendicular to the direction δ previously detected (210).

The foregoing description of specific exemplary embodiments will so fully reveal the invention according to the conceptual point of view, so that others, by applying current knowledge, will be able to modify and/or adapt in various applications the specific exemplary embodiments without further research and without parting from the invention, and, accordingly, it is meant that such adaptations and modifications will have to be considered as equivalent to the specific embodiments. The means and the materials to realise the different functions described herein could have a different nature without, for this reason, departing from the field of the invention, it is to be understood that the phraseology or terminology that is employed herein is for the purpose of description and not of limitation.

CLAIMS

1. A method for defining a lay direction δ of at least one elongated buried object (50) by means of GPR technique (Ground Penetrating Radar), said method **characterized in that** it comprises the steps of:

- moving a first GPR sensor (110) along a first trajectory s consisting of a plurality of points P, said first trajectory s having origin at a predetermined point P_0 and having as tangent line, at each point P of said plurality, a predetermined direction y;
- moving a second GPR sensor (110'), integrally to said first GPR sensor (110), so that said second GPR sensor (110') travels along a second trajectory s' consisting of a plurality of points P', said second trajectory s' having origin at a predetermined point Po' and being parallel to said first trajectory s, said second trajectory s' having as tangent line, at each point P' of said plurality, a predetermined direction y', said second GPR sensor (110') spatially arranged in such a way that a connecting line between said first GPR sensor (110) and said second GPR sensor (110') defines a predetermined direction ε not parallel to said directions y and y';
- detecting a first plurality of presence signals

by said first GPR sensor (110), each presence signal of said first plurality being detected at least at one point P of said first trajectory s, said first plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object (50) at a first area (A) defined in a neighbourhood of a projection of said point P on said elongated buried object (50) ;

— determining a first set of spatial coordinates for each point P of said trajectory s in which a presence signal of said first plurality is detected;

- detecting a second plurality of presence signals by said second GPR sensor (110'), each presence signal of said second plurality being detected at least at one point P' of said second trajectory s', said second plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object (50) at a second area (A') defined in a neighbourhood of a projection of said point P' on said elongated buried object (50), said or each second area (A') being spatially different from said or each first area (A) ;

- determining a second set of spatial coordinates for each point P' of said second trajectory s' in which a presence signal of said second plurality is detected;

- receiving by a control unit (150) said first and said second plurality of presence signals and each said first and said second set of spatial coordinates ;

- computing a presence record concerning the presence of possible buried elongated objects (50) and of each said first and said second set of spatial coordinates, by:

  determining, among all points P and P' at which a presence signal has been detected, points P_i and P_1' at which the probability of presence of said or each elongated buried object (50) is higher; and

  comparing said sets of spatial coordinates corresponding to said points P_i and P_i' with each other;

- determining, at the end of said computing step, the lay direction δ of at least one elongated buried object responsive to the set of spatial coordinates corresponding to points of said lay direction δ of at least one elongated buried object (50) responsive to said set of spatial coordinates corresponding to said points P_i and P_i' .

2. The method according to claim 1, wherein said

computing step comprises a step of computing an angle a set between a direction x orthogonal to said directions y and y' and an expected lay direction δ_1 of said or each elongated object (50), said expected lay direction δ_1 computed by comparison of set of spatial coordinates of said points P_i and P_i' in which data have been detected relative to the presence of a same elongated buried object (50).

3. The method according to claim 2, wherein the method further comprises the steps of:

- further positioning said apparatus (100) in such a way that said direction y is orthogonal to said expected lay direction δ_1;
- iterating said steps of:
  - detecting said first plurality of presence signals;
  - determining said first set of spatial coordinates of each point P;
  - detecting said second plurality of presence signals;
  - determining said second set of spatial coordinates of each point P';
  - receiving said first and said second plurality of presence signals and of said first and said second set of spatial coordinates;

computing said angle a;

said step of iterating repeated until said angle a is zero;

- identifying, when said angle a is zero, said expected lay direction δ_1 as said lay direction δ.

4. The method according to claim 1, wherein said set of spatial coordinates of each point P is referred to a reference system selected from the group consisting of:

- a relative reference system having origin at said predetermined point P_0;
- a global reference system;
- or a combination thereof;

and wherein said set of spatial coordinates of each point P' is referred to a reference system selected from the group consisting of:

- a relative reference system having origin at said predetermined point P_0';
- a global reference system;
- or a combination thereof.

5. An apparatus (100) for defining a lay direction δ of at least one elongated buried object (50), said apparatus (100) comprising:

- a first GPR sensor (110) configured to measure a first plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object (50);

said apparatus (100) **characterized in that** it further comprises :

– a second GPR sensor (110') arranged integrally to said first GPR sensor (110) in such a way that a connecting line between said first GPR sensor (110) and said second GPR sensor (110') defines a predetermined direction ε not parallel to said directions y and y', said second GPR sensor (110') configured to measure a second plurality of presence signals associated with data concerning the presence of at least one possible elongated buried object (50) ;

– at least one position sensor (120) arranged to detect a first set of spatial coordinates for each point P of said trajectory s in which a presence signal of said first plurality is detected, said or each position sensor (120) being also arranged to detect a second set of spatial coordinates for each point P' of said second trajectory s' in which a presence signal of said second plurality is detected;

– a control unit (150) arranged for receiving said first and said second plurality of presence signals from said first and said second GPR sensor (110,110') and each said first and said second set of spatial coordinates from said or each position sensor (120).

6. The apparatus (100) according to claim 5, wherein a program means is also comprised resident in said control unit (150) and configured to analyse each said first and said second set of spatial coordinates and said data concerning the presence of possible buried elongated objects (50), said control unit (150) being also configured for:

determining, among all points P and P' at which a presence signal has been detected, points P_1 and P_1' at which the probability is higher of presence of said or each elongated buried object (50); and

comparing said sets of spatial coordinates corresponding to said points Pi and Pi' with each other;

- determining, at the end of said computing step, said lay direction δ of at least one elongated buried object (50) responsive to said set of spatial coordinates corresponding to said points Pi and Pi'.

7. The apparatus (100) according to claim 5, where a navigation device is also provided (160), operatively connected to said control unit (150), and arranged to guide said first GPR sensor (110) and said second GPR sensor (110') in such a way that said directions y and y' turn out parallel or orthogonal to said lay direction δ of said or each elongated object (50), in order to allow defining the whole lay direction of said or each elongated object (50), in particular said navigation device (160) selected from the group consisting of:

- an analog compass;
- a digital compass;
- an accelerometer;
- a GPS device;
- a total station;
- a gyroscope;
- an inertial station;
- a combination thereof.

8. The apparatus (100) as claim 6 and 7, wherein said navigation device is configured to guide said first GPR sensor (110) and said second GPR sensor (110') orthogonally to an expected lay direction δ_ι and said program means is configured to determine, at the end of said computing step carried out by said program means, a lay direction δ, and to check that it coincides with said expected lay direction δ_ι.

9. The apparatus (100) according to claim 5, wherein said or each position sensor (120) is selected from the

group consisting of:

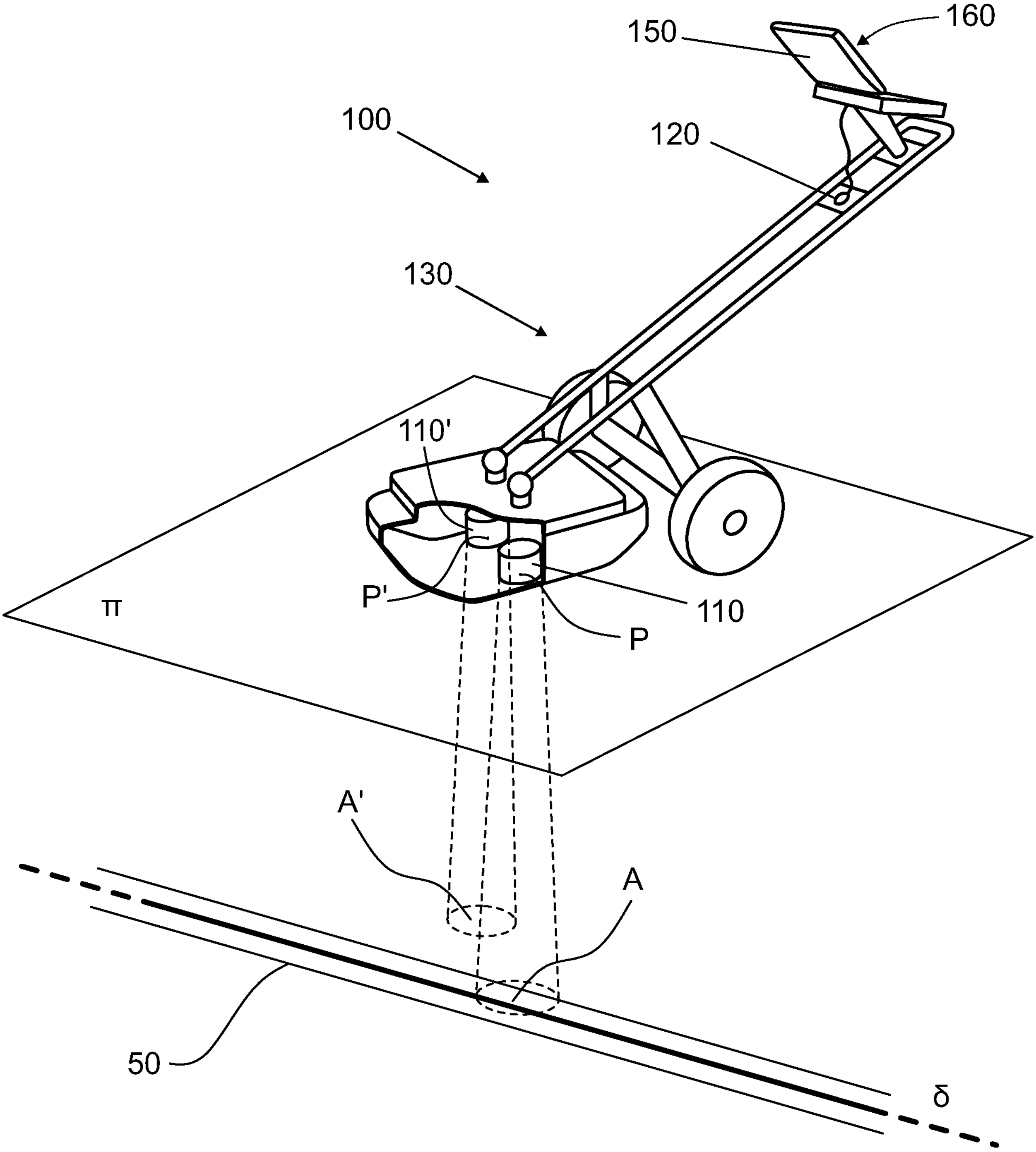
- a rotational encoder;
- a metric wheel;
- a GPS device;
- a total station;
- a gyroscope;
- an inertial station;
- a measuring device of the travelled distance;
- a combination thereof;

and wherein said first and/or said second GPR sensor (110,110') is/are selected from the group consisting of:

- an element type antenna (i.e. monopole, dipole, bow-tie, etc .);
- an antenna of "frequency independent" type (i.e. Logperiodic, spiral-shaped, Vivaldi, etc.);
- a horn antenna;
- an ultra-wide band non dispersive antenna (i.e. travelling wave antenna, travelling wave TEM horn, Impulse Radiating Antenna, rod antenna, etc.)
- a combination thereof.

10. The apparatus (100) according to claim 5, wherein a movable support is also provided (130) arranged to support said first GPR sensor (110) and said second GPR sensor (110') to assist that said GPR sensors are moved integrally to each other.

Fig. 1



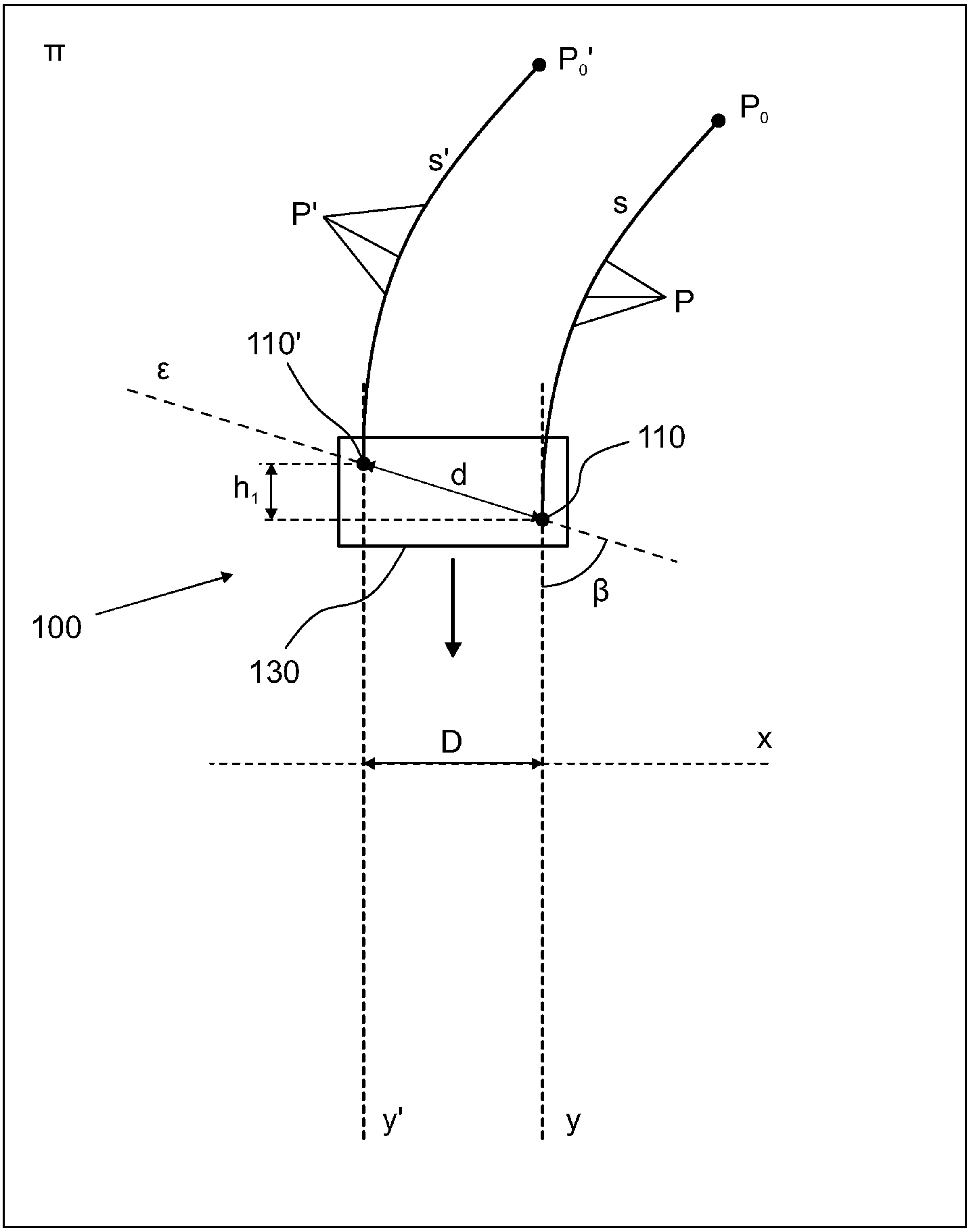
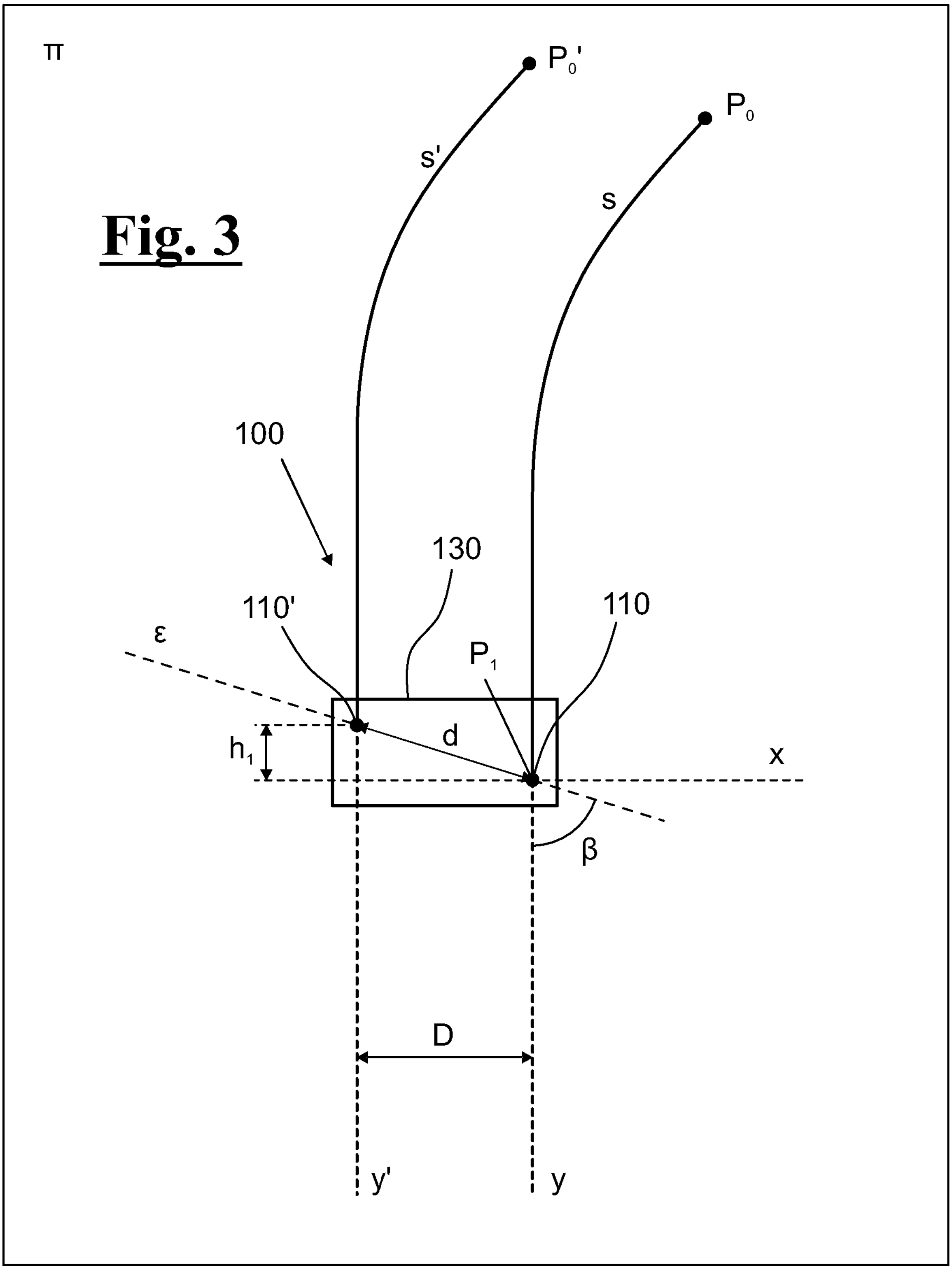


Fig. 2

Fig. 3



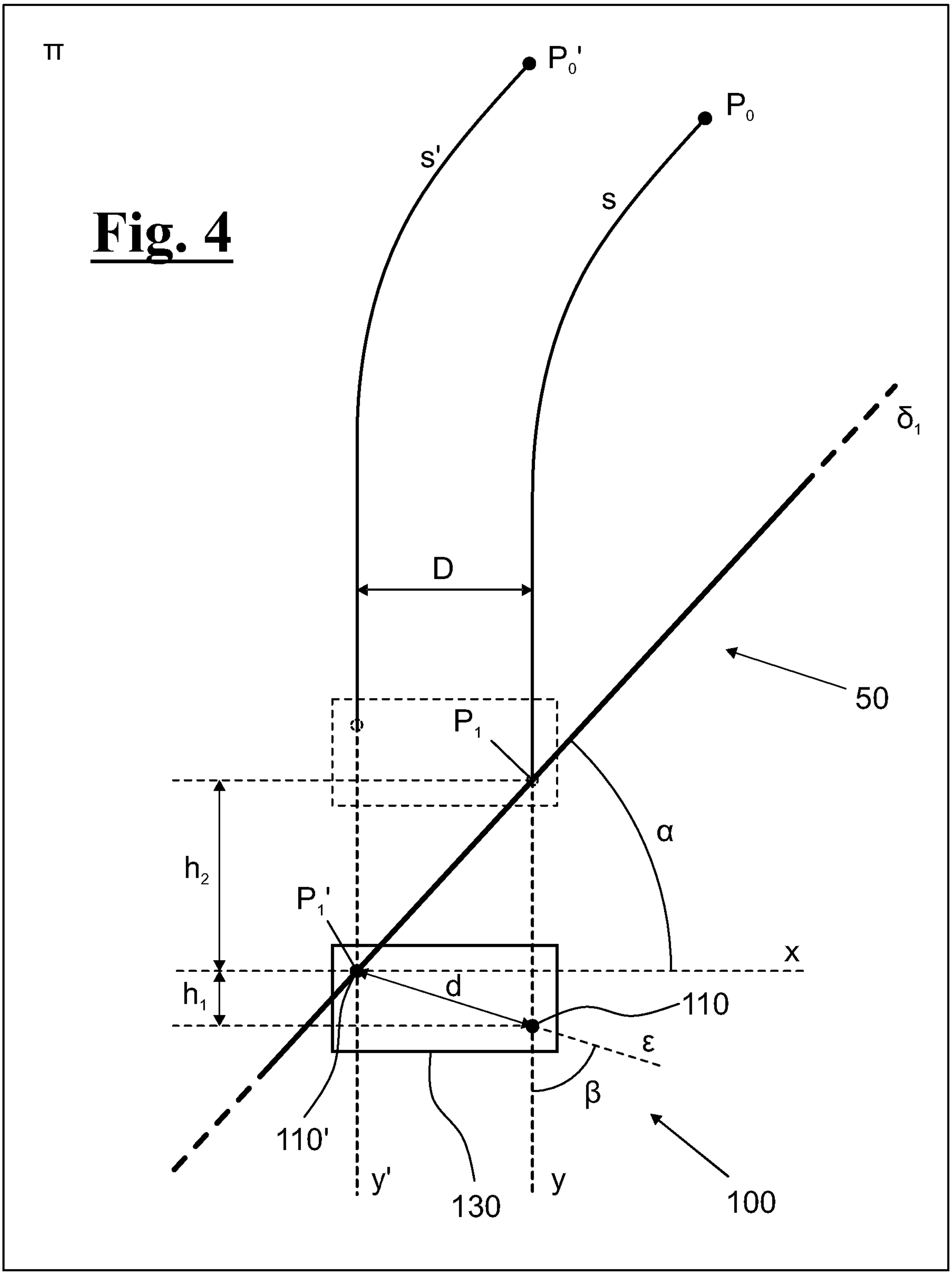
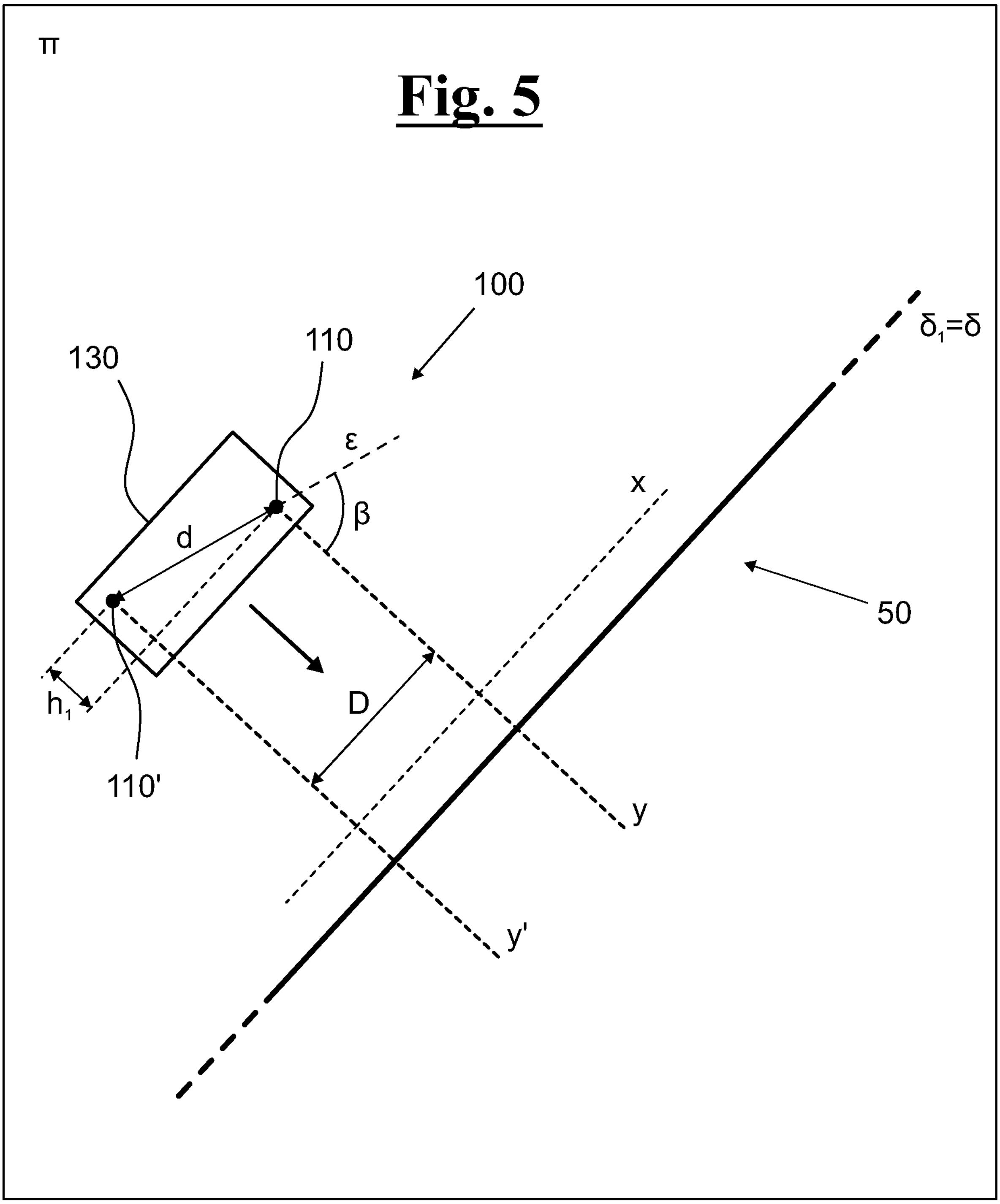

π
Fig. 4
P₀'
P₀
s'
s
δ₁
D
50
P₁
α
h₂
P₁'
x
d
110
h₁
ε
β
110'
y'
130
y
100

Fig. 5



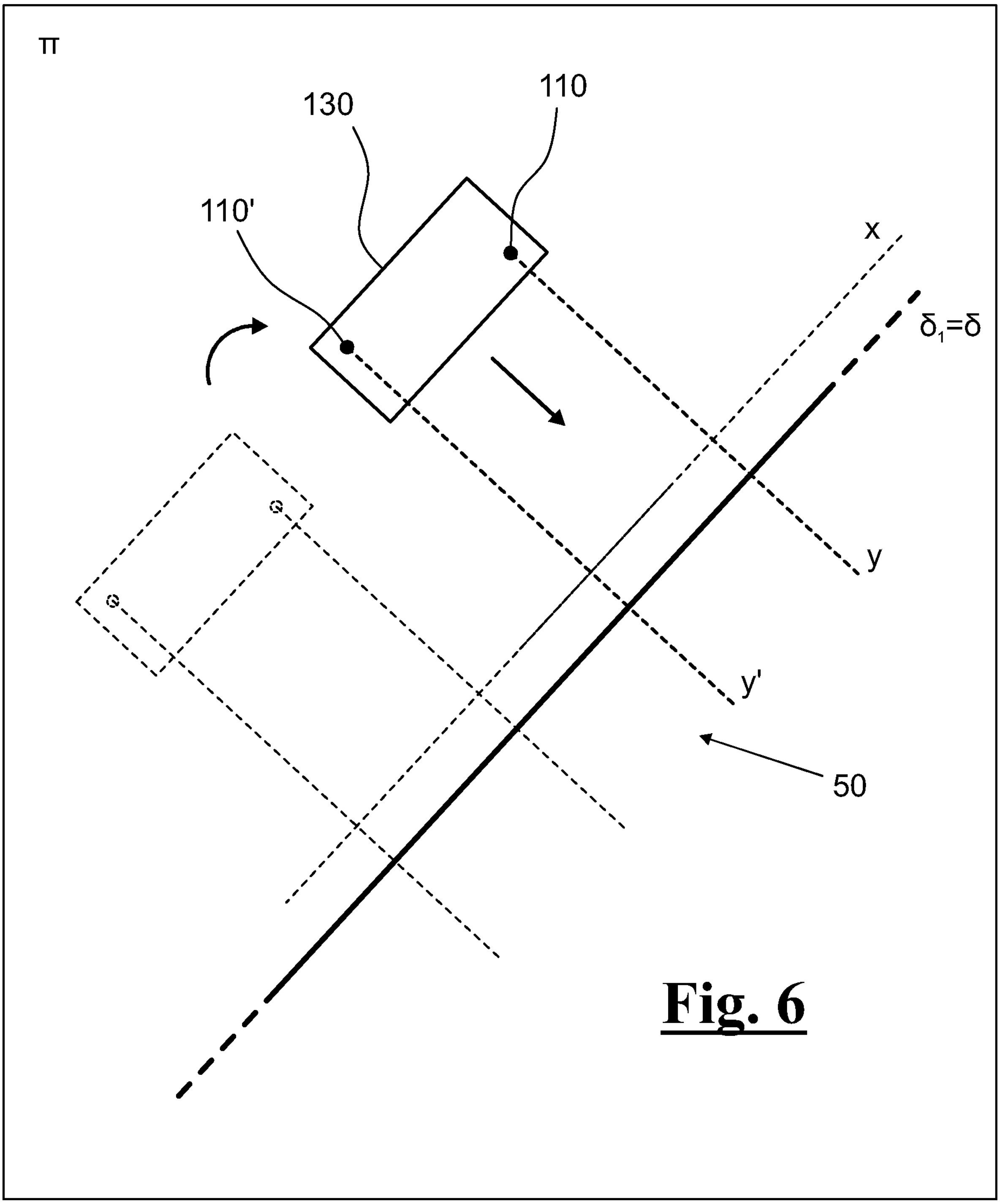


Fig. 6

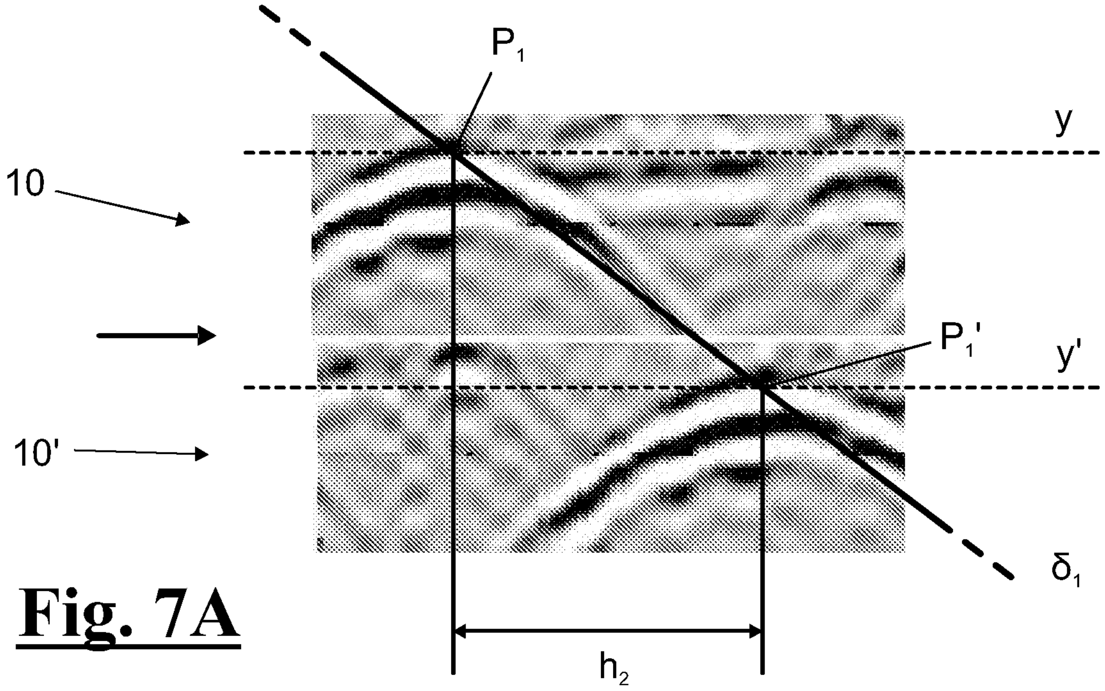


Fig. 7A

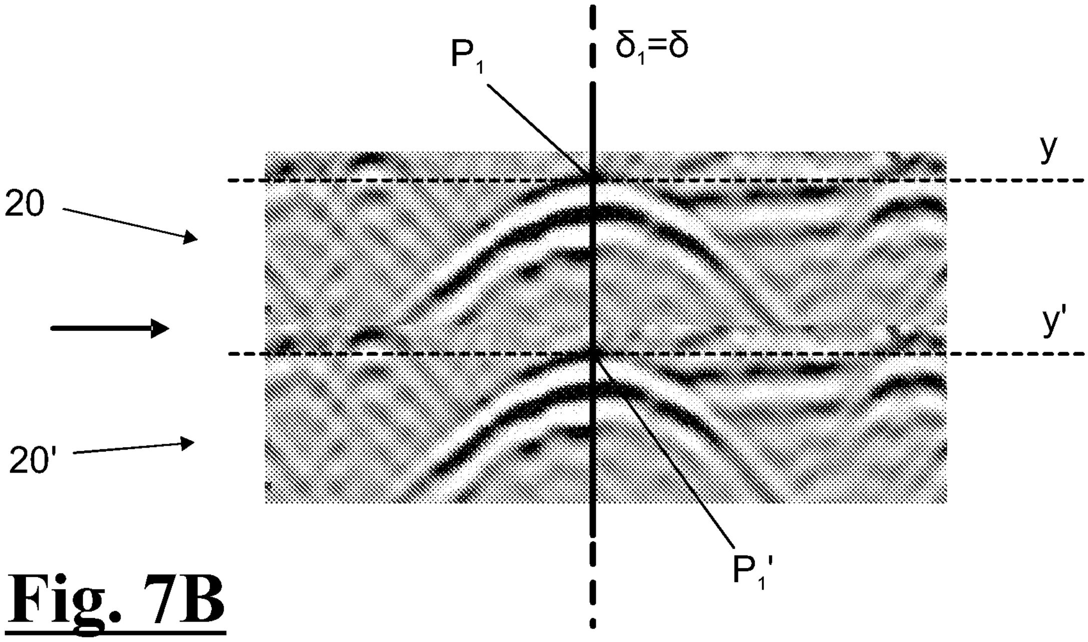
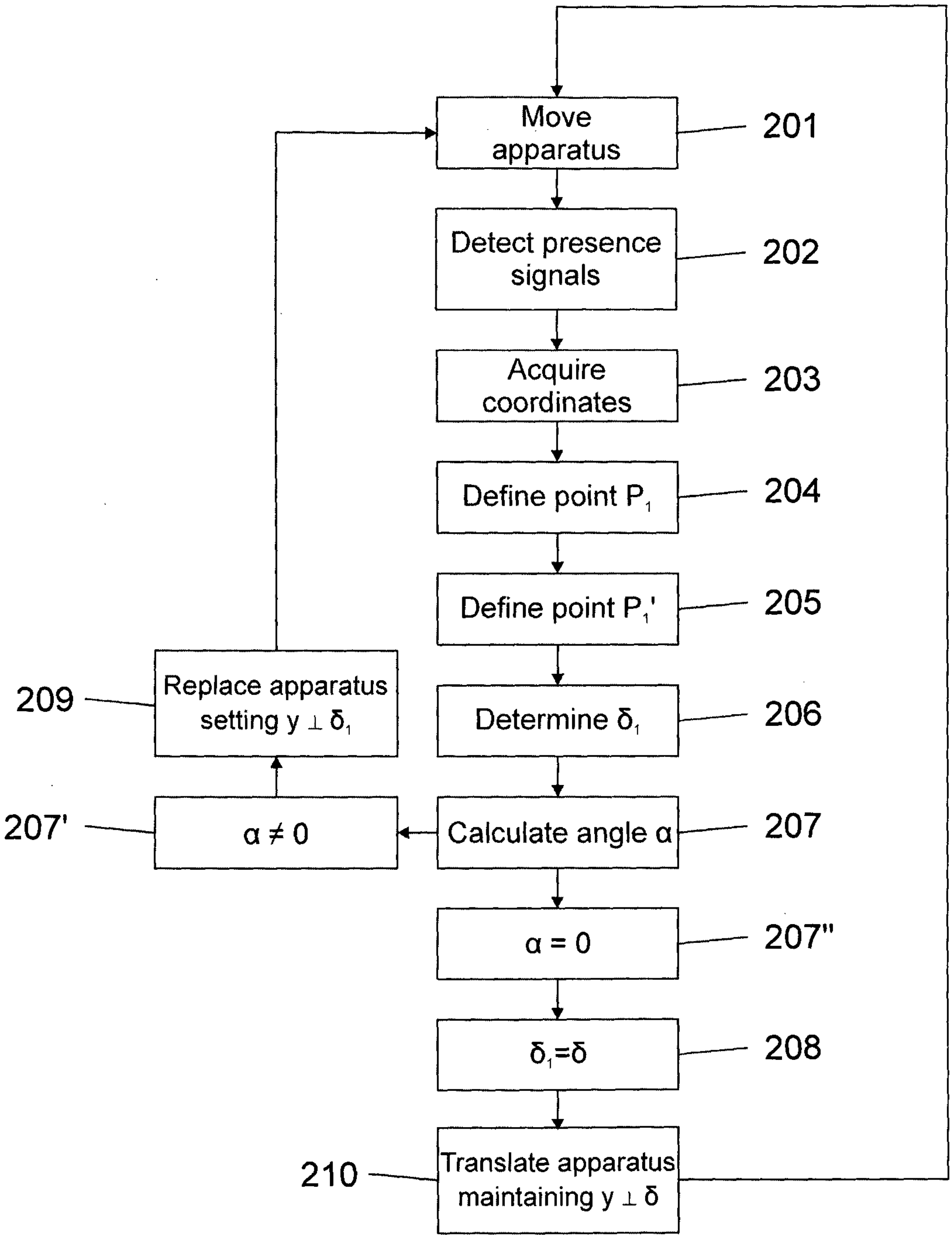


Fig. 7B

Fig. 8


Move apparatus
201
Detect presence signals
202
Acquire coordinates
203
Define point P_1
204
Define point P_1'
205
Determine δ_1
206
Replace apparatus setting $y \perp \delta_1$
209
$\alpha \neq 0$
207'
Calculate angle α
207
$\alpha = 0$
207"
$\delta_1 = \delta$
208
Translate apparatus maintaining $y \perp \delta$
210