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CA 2370151 A1 2000/11/09

(21) 2 370 151

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 1999/05/03
(87) Date publication PCT/PCT Publication Date: 2000/11/09
(85) Entrée phase nationale/National Entry: 2001/11/05
(86) N° demande PCT/PCT Application No.: CH 1999/000183
(87) N° publication PCT/PCT Publication No.: 2000/066971

(51) Cl.Int.^{7}/Int.Cl.^{7} G01B 11/16, A61B 6/00
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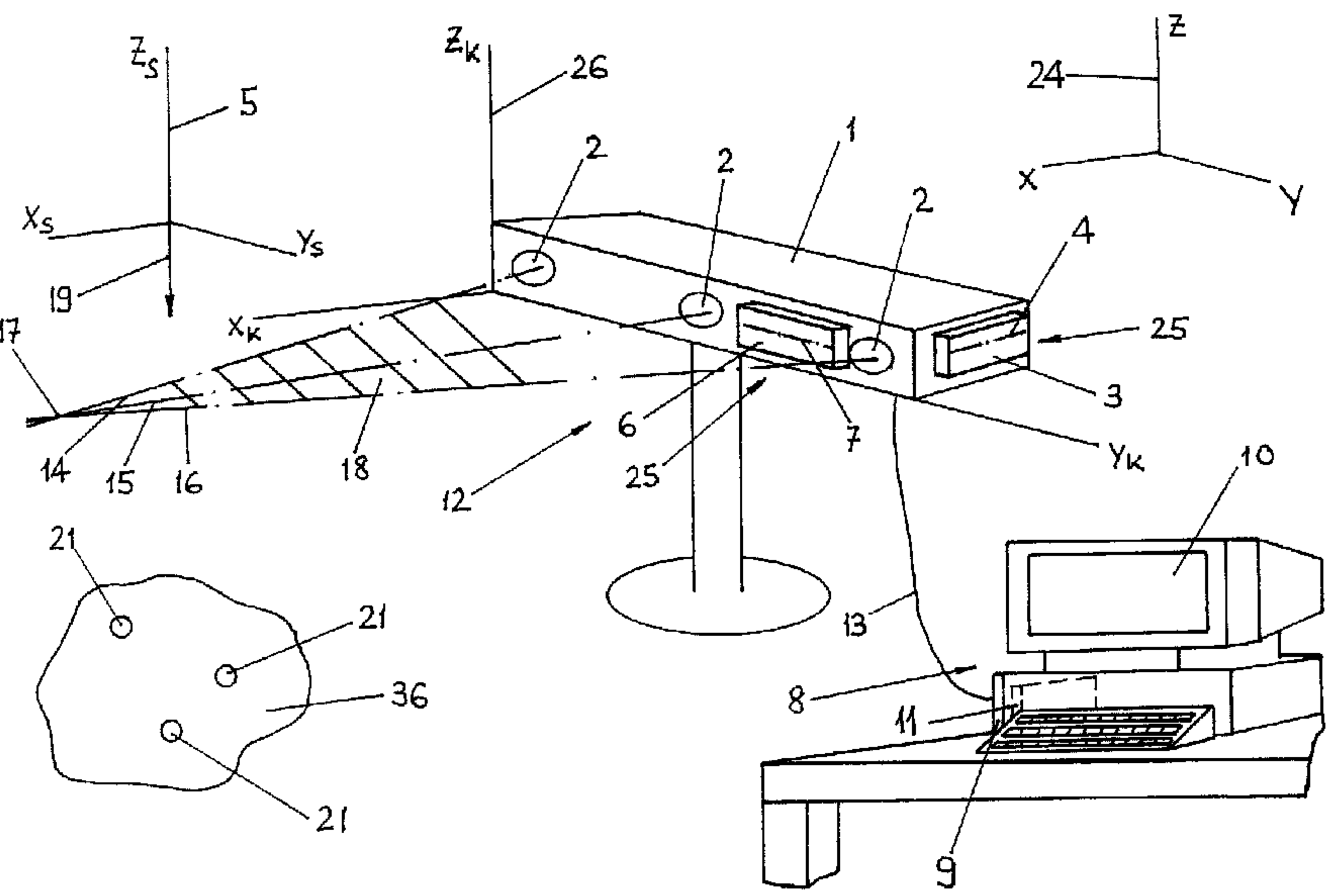
(54) Titre : DISPOSITIF DE DETECTION DE POSITION DOTE DE MOYENS AUXILIAIRES PERMETTANT DE DETERMINER LA DIRECTION DU VECTEUR DE GRAVITE

(54) Title: POSITION DETECTOR WITH AUXILIARY MEANS FOR DETECTING THE DIRECTION OF THE GRAVITY VECTOR



(57) Abrégé/Abstract:
The invention relates to a device for detecting the position and orientation of a body (36) within at least one three-dimensional system of co-ordinates (5; 24). The inventive device comprises A) a position detecting sensor (1) and B) a computer (8) that is connected to the position detecting sensor (1) for detecting the position and orientation of a body (36) within at least one system of co-ordinates (5; 24; 26), whereby C) the device comprises auxiliary means (25) for detecting the direction of the gravity vector (19). The invention also relates to a method for correcting the defects in magneto-optical X-ray photographs (35). Said defects occur caused by influences related to gravity and the terrestrial magnetic field. Said method comprises the steps: a) detecting the direction of the gravity vector (19), b) detecting the position and orientation of the X-ray apparatus (28), c) detecting the distortions of the X-ray photograph (35), whereby said distortions are produced by gravity-related, mechanical deformations of the X-ray apparatus (28), d) detecting the defects in the X-ray photograph (35), whereby said defects are caused by the local terrestrial magnetic field, e) detecting the optical deformations of the X-ray photograph (35), whereby said deformations occur in the receiver (29) and f) correcting the digitised X-ray photograph by means of a computer (8) in relation to the defects detected in the steps d), e) and f).

Abstract:

A device for detecting the position and orientation of a body (36) within at least one three-dimensional coordinate system (5;24;26) including

A) a position sensor (1); and

B) a computer (8) connected to the position sensor (1) for determining the position and orientation of a body (36) within at least one coordinate system (5;24;26),

C) said device comprising auxiliary means (25) for determining the direction of the gravity vector (19).

A method for correcting magneto-optical X-ray photographs (35) with respect to shortcomings arising from deformations caused by gravity or the Earth's magnetic field, including the following steps:

a) detecting the direction of the gravity vector (19);

b) determining the position and orientation of the X-ray apparatus (28);

c) determining the distortions of the X-ray photograph (35) due to gravity-induced, mechanical deformations of the X-ray apparatus (28);

d) determining the shortcomings of the X-ray photograph (35) caused by the Earth's local magnetic field;

e) determining the optical deformations of the X-ray photograph (35) occurring in the receiver (29); and

d) correcting the digitized X-ray photograph with respect to the shortcomings determined in steps c), d), and e) by means of a computer (8).

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English translation of the International Patent Application No. PCT/CH99/00183 „Position detector with auxilliary means for detection of the gravity vector" in the name of Synthes AG Chur

Position detector with auxiliary means for detecting the direction of the gravity vector

The invention relates to a device for detecting the position and orientation of bodies provided each with at least three non-collinear markers within at least one three-dimensional coordinate system as claimed in the precharacterising part of claim 1, and to a method for the correction of X-ray photographs as claimed in the precharacterising part of claim 24.

The use of measuring instruments and imaging appliances which are mobile in space often necessitates changes in the position or orientation of the measuring instrument, depending on the kind of measurement to be taken. This is also true of X-ray apparatuses, particularly of the mobile or swivel-mounted X-ray apparatuses commonly used in surgery (image intensifiers, c-arm appliances).

A system for detecting the position and orientation of a surgical instrument or device within an object and for simultaneously displaying previously generated images of said object corresponding to the detected position is known from US Patent No. 5,383,454 to BUCHHOLZ. This system also permits to move the tip of a probe to a defined position within an object, the location of the probe being observable on a single display screen which simultaneously displays also a previously generated image of this part of the object. In this known invention, the position of the probe is determined by means of a three-dimensional sound digitizer.

With heavy apparatuses such as X-ray apparatuses used in surgery, the orientation of the apparatus relative to the gravitational field of the Earth may have an influence, due to material deformations, on the measurement and, consequently, on the digitization of the image. With X-ray apparatuses using magneto-optical image digitization the orientation of the apparatus relative to the Earth's magnetic field may also have a negative effect on the X-ray photographs. A further possible deformation of these X-ray photographs may be due to the influence of optical deformations occurring in the receiver, depending primarily on the composition of the radiation source and on the nature of the receiver, which may arise, for example, during the transformation of electrons into photons or during a subsequent transformation of the photons into an electrical signal.

The invention is intended to provide a remedy for this. It is accordingly an object of the invention to proceed, in addition, to a measurement in situ of the local gravity vector and to determine the corrections to be made concerning the influence of gravity-induced deformations of the X-ray apparatus, which are different depending on whether the X-ray apparatus is oriented horizontally or vertically, as well as the influences of gravity and of the

Earth's magnetic field on the measured values or the X-ray photographs.

According to the invention, this object is achieved by means of a device for detecting the position and orientation of bodies provided each with at least three non-collinear markers within at least one three-dimensional coordinate system which shows the features of claim 1, and of a method for the correction of X-ray photographs which shows the features of claim 24.

Further advantageous embodiments of the invention are characterised in the dependent claims.

The position detector with auxiliary means for detecting and referencing the gravity vector according to the invention comprises essentially an optoelectronic sensor detecting the position of markers, preferably infrared light-emitting diodes (IREDs), within a coordinate system, which is connected to a computer for analyzing the signals received by the sensor, and auxiliary means detecting the direction of the gravity vector relative to said three-dimensional coordinate system and permitting a computerized coordinate transformation between a sensor-based coordinate system and a space-based or gravity-based coordinate system.

Instead of the optoelectronic position detector, the device according to the invention may also comprise an acoustic or a magnetic position detection unit.

Depending on the selected position detection unit, the markers may be transmitters, receivers, or reflectors. For example, the following elements are conceivable as transmitters:

- light sources;
- light-emitting diodes (LEDs);
- infrared light-emitting diodes (IREDs);
- acoustic transmitters;
- coils for generating a magnetic field; or
- reflectors combined with corresponding transmitters arranged in a separate unit located at a distance from said reflectors;

or as receivers:

- CCD-cameras;
- photodiodes;
- microphones; or
- Hall effect components.

In a preferred embodiment of the device according to the invention, said device comprises a position sensor with at least two optoelectronic cameras which are preferably equipped with CCD chips (charge-coupled device chips), a first inclinometer the horizontal axis of which defines the x-axis of a gravity-based, three-dimensional coordinate system, a second inclinometer the horizontal axis of which defines the y-axis of a gravity-based, three-dimensional coordinate system, and a computer which is equipped with software permitting a three-dimensional, real-time viewing of the data on a display screen in a numeric or graphic form. The horizontal axes of the inclinometers form a plane extending perpendicularly to the gravity vector and which is combined with the gravity vector so as to form a three-dimensional, gravity-based coordinate system. By means of an electronic transmission of the signals emitted by the inclinometers to the computer, it is possible to determine a deviation in parallelism between one axis of the sensor-based coordinate system and the corresponding axis of the gravity-based coordinate system, and, consequently, to determine the rotation(s) of the sensor-based coordinate system relative to the gravity-based coordinate system.

Under favourable conditions, the plane extending perpendicularly to the gravity vector may also be determined with the aid of only one inclinometer.

The inclinometers may be appliances based on either one of the principles of gas bubble and liquid (spirit level), of gyration (by analogy with the gyrocompass), or of inertia (by analogy with inertial position detection) capable of electronically determining deviations from the gravity vector. Appliances based on the principles of gyration or of inertia need to be previously calibrated with respect to their orientation relative to the gravity vector. The use of magnetic appliances (by analogy with the electronic compass) is equally possible.

As a position detector, any commercially available system, for example an OPTOTRAK 3020 System put on the market by Northern Digital, Waterloo, Ont., may be used.

A further embodiment of the device according to the invention differs from the embodiment described above only in so far as the detection of the gravity vector is realised by means of a body aligning itself with the Earth's gravitational field. Said body is suspended on a thin thread or wire and is equipped with at least two markers arranged at a distance A from each other. The positions of the markers are detected by the position detector, thus making it possible to determine the positions of the markers in space and, consequently, the direction of the gravity vector by means of the computer. The direction of the gravity vector within the sensor-based coordinate system is detected by the position detector and the rotation(s) of the sensor-based coordinate system relative to the gravity-based coordinate system is (are) determined by the computer by means of digital data processing.

Instead of the suspension of the body aligning with the gravitational field on a thread or a wire, it is also possible to envisage a suspension on a chain, a cardanic suspension, a ball-and-socket bearing, or an embedding of the body in an elastomer, such as silicone rubber or foamed silicone rubber.

Preferably, the alignment of the body with the gravitational field is shock-absorbed, said absorption being realisable by mechanical or electromagnetic means, by immersion of the body into a liquid, by means of springs or by means of shock absorbers based on air pressure or gas pressure.

The method of the invention for detecting the precise orientation in the gravitational field of an X-ray apparatus provided with markers by means of an X-ray source and a receiver generating an X-ray photograph, preferably a magneto-optical X-ray photograph, comprises the following steps:

a) detecting and saving the direction of the gravity vector within a three-dimensional coordinate system by means of an embodiment of the device according to the invention, said coordinate system being sensor-based, space-based, or gravity-based;

b) determining the position of the X-ray source and the receiver within said coordinate system by means of an embodiment of the device according to the invention;

c) determining the distortions of the X-ray photograph due to gravity-induced, mechanical deformations of the X-ray apparatus by means of the computer; and

d) correcting the X-ray photograph with respect to the distortions determined in step c) by means of the computer.

In a preferred embodiment of the method according to the invention, said method further comprises the following steps:

e) determining the direction of the normal extending perpendicularly to the X-ray photograph within said coordinate system from the position and orientation of the receiver or the X-ray source as determined in step b) by means of the computer;

f) determining the shortcomings of the X-ray photograph generated by the receiver on a magneto-optical basis caused by the deviation of the normal of said photograph from the direction of the Earth's local magnetic field by means of the computer; and

g) correcting the X-ray photograph with respect to the shortcomings determined in step f) by means of the computer.

In another embodiment of the method according to the invention, said method further comprises the following steps:

h) determining the shortcomings of the magneto-optical X-ray photograph which are caused by optical deformations occurring in the receiver;

i) correcting the X-ray photograph with respect to the shortcomings determined in step h) by means of the computer.

The advantages achieved by the present invention consist essentially in the fact that the device according to the invention allows to detect the local gravity vector in situ and that the method according to the invention allows to determine corrections which take into account the distortions of the X-ray photograph due to gravity-induced, mechanical deformations of the X-ray apparatus. This is particularly true of swivel-mounted X-ray apparatuses, in which the mechanical deformations are different depending on whether the X-ray apparatus is oriented horizontally or vertically. In addition, the influences of gravity and of the Earth's magnetic field on the X-ray photographs may also be determined and the image accordingly corrected. A further advantage of the invention is that no calibration instrument needs to be arranged in the path of the rays, so that the operation is not affected by such an instrument.

In the following, the invention and further developments of the invention will be illustrated in greater detail with reference to the partially diagrammatic representations of several embodiments.

In the drawings:

Fig. 1 is a diagrammatic representation of a preferred embodiment of the device according to the invention;

Fig. 2 is a diagrammatic representation of another preferred embodiment of the apparatus according to the invention; and

Fig. 3 is an illustration of a preferred way of carrying out the method according to the invention.

Fig. 1 shows a preferred embodiment of the device according to the invention. The device comprises a position sensor 1 with three optoelectronic cameras 2, which are preferably equipped with linear CCD chips (charge-coupled device chips), a first inclinometer 3 fastened to the position sensor 1, the horizontal axis 4 of which defines the x-axis of a gravity-based, three-dimensional coordinate system 5, a second inclinometer 6 fastened to the position sensor 1, the horizontal axis 7 of which extends perpendicularly to said horizontal axis 4 and forms the y-axis of the gravity-based, three-dimensional coordinate system 5, and a computer 8. For processing the signals detected by the cameras 2, the position detector 12 (for example an OPTOTRAK 3020, Northern Digital, Waterloo, Ont.) is equipped with a System Control Unit 9 connected with the computer 8, cables 13, an interface card 11, and with software for three-dimensionally displaying the data in real-time on the display screen 10 in a numeric or graphic form. The optical axes 14;15;16 of the cameras 2 intersect each other at a point 17 and form a plane 18 which extends perpendicularly to the gravity vector 19 as the coordinate axis X_K of the sensor-based, three-dimensional coordinate system 26 is aligned parallel to the horizontal axis 4 of the first inclinometer 3 and the coordinate axis Y_K of the sensor-based, three-dimensional coordinate system 26 is aligned parallel to the horizontal axis 7 of the second inclinometer 6. In case of a deviation in parallelism between one of the sensor-based coordinate axes $X_K Y_K$ and the corresponding horizontal axes 4;7 of the inclinometers 3;6 said deviation is detected by the inclinometers 3;6 and the rotation(s) of the sensor-based coordinate system 26 relative to the gravity-based coordinate system 5 is (are) determined by the computer 8 by means of digital processing of the signals corresponding to the deviations detected by the inclinometers 3;6.

Fig. 2 shows another preferred embodiment of the device according to the invention which differs from the embodiment shown in Fig. 1 only in so far as the detection of the gravity vector 19 is realised by means of a body 20 aligning with the gravitational field. Said body 20 is suspended on a thin thread or wire 22 and is equipped with at least two markers 21, preferably infrared light-emitting diodes (IREDs), arranged at a distance A from each other. The infrared light emitted by the markers 21 is detected by the cameras 2 of the position detector 12, thus making it possible to determine the positions of the markers 21 in space and, consequently, the direction of the gravity vector 19 by means of the computer 8. In case of a deviation in parallelism between the sensor-based normal 23 extending perpendicularly to the plane 18 formed by the optical axes 14;15;16 of the cameras 2 and the gravity vector 19, said deviation is detected by the position sensor 1 and the rotation(s) of the sensor-based coordinate system 26 relative to the gravity-based coordinate system 5 is (are) determined by the computer 8 by means of digital processing of the signals corresponding to the deviation detected by the position sensor 1.

Fig. 3 illustrates the method of the invention for detecting the precise orientation of an X-ray apparatus 28 by means of the device according to the invention. The X-ray apparatus comprises essentially an X-ray source 30 and a receiver 29 which on a magneto-optical basis generates an X-ray photograph 35 extending vertically to the normal 31;32 of the photograph. The X-ray photographs 35 of the patient 33 are essentially taken in an anterior-posterior and a lateral-medial direction, or vice versa, so that the normal 31;32 of the photograph extends approximately in a vertical or horizontal direction, depending on the position of the X-ray apparatus 28. The method according to the invention comprises the following steps:

a) detecting and saving the direction of the gravity vector 19 within a three-dimensional coordinate system 5;24;26 by means of the position detector 12 and the computer 8. A space-based coordinate system 24 may be determined by measuring the positions of at least three non-collinear markers 21 having a fixed position in space by means of the position detector 12, while the determination of the gravity-based, three-dimensional coordinate system 5, which is equally space-based, may be realised by measuring the positions of the horizontal axes 4;7 of the inclinometers 3;6 and their point of intersection, or by measuring the positions of at least three markers 21 provided in a non-collinear arrangement on the body 20;

b) determining the position and orientation of the X-ray source 30 and/or the receiver 29 within said coordinate system 5;24;26 by means of the position detector 12 and the computer 8 by measuring the positions of the markers 21 fixed on the X-ray source 30 and/or the receiver 29;

c) determining the distortions of the X-ray photograph due to gravity-induced, mechanical deformations of the X-ray apparatus 28 by means of the computer 8;

d) correcting the X-ray photograph with respect to the distortions determined in step c) by means of the computer 8;

e) determining the direction of the normal 31;32 extending perpendicularly to the X-ray photograph within said coordinate system 5;24;26 from the position and orientation of the receiver 29 as determined in step b) by means of the computer 8;

f) determining the shortcomings of the X-ray photograph generated by the receiver 29 on a magneto-optical basis arising from the deviation of the normal 31;32 of said photograph from the direction of the Earth's local magnetic field by means of the computer 8;

g) correcting the X-ray photograph with respect to the shortcomings determined in step f) by means of the computer 8;

h) determining the shortcomings of the magneto-optical X-ray photograph 35 which are caused by optical deformations occurring in the receiver 29 and which are particularly affected, among other things, by the vertical or horizontal orientation of the X-ray apparatus 28;

i) correcting the X-ray photograph 35 with respect to the shortcomings determined in step h) by means of the computer 8.

Claims

1. A device for detecting the position and orientation of a body (36) provided with at least three non-collinear markers (21) within at least one three-dimensional coordinate system (5;24;26) including

A) a position sensor (1) for locating markers (21) within said coordinate system (5;24;26) or within another three-dimensional coordinate system (5;24;26); and

B) a computer (8) for determining the position and orientation of a body (36) provided with at least three non-collinear markers (21) within at least one coordinate system (5;24;26) from the places of the markers (21) as detected by the position sensor (1),

characterized in that

C) the device comprises auxiliary means (25) for determining the direction of the gravity vector (19) within a coordinate system (5;24;26).

2. A device as claimed in claim 1, characterised in that the auxiliary means (25) comprise at least one inclinometer (4).

3. A device as claimed in claim 2, characterised in that the auxiliary means (25) comprise two inclinometers (3;6) which are fastened to the position sensor (1) in such a way that their horizontal axes (4;7) extend perpendicularly to each other.

4. A device as claimed in claim 2 or 3, characterised in that the inclinometer(s) (3;6) is (are) based on the principle of gas bubble and liquid, by analogy with a spirit level, and electronically detect(s) deviations of

the horizontal axes (4;7) relative to the gravity vector (19).

5. A device as claimed in claim 2 or 3, characterised in that the inclinometer(s) (3;6) is (are) based on the principle of gyration with a space-based vector of angular momentum, by analogy with a gyrocompass, and electronically detect(s) deviations of the calibrated horizontal axes (4;7) relative to the gravity vector (19).

6. A device as claimed in claim 2 or 3, characterised in that the inclinometer(s) (3;6) is (are) based on the principle of inertia, by analogy with inertial position detection, and electronically detect(s) deviations of the calibrated horizontal axes (4;7) relative to the gravity vector (19).

7. A device as claimed in claim 1, characterised in that the auxiliary means (25) comprise a body (20) suspended in space and aligning with the local gravitational field, said body being equipped with at least two markers (21) arranged at a distance A from each other.

8. A device as claimed in claim 7, characterised in that the suspension (27) of the body (20) is realised by means of a thin thread or wire (22).

9. A device as claimed in claim 7, characterised in that the suspension (27) of the body (20) is realised by means of a chain.

10. A device as claimed in claim 7, characterised in that the suspension (27) of the body (20) is a cardanic suspension.

11. A device as claimed in claim 7, characterised in that the suspension (27) of the body (20) is realised by means of a ball-and-socket bearing.

12. A device as claimed in claim 7, characterised in that the suspension (27) of the body (20) in space is realised by means of an embedding of the body (20) in an elastomer.

13. A device as claimed in claim 12, characterised in that the elastomer is a silicone rubber.

14. A device as claimed in claim 13, characterised in that the body (20) is embedded in a foamed silicone rubber.

15. A device as claimed in any of the claims 7 to 14, characterised in that the alignment of the body (20) with the gravitational field is shock-absorbed.

16. A device as claimed in claim 15, characterised in that the alignment of the body (20) with the gravitational field is shock-absorbed by means of an immersion of said body (20) into a liquid.

17. A device as claimed in claim 15, characterised in that the alignment of the body (20) with the gravitational field is shock-absorbed by means of springs.

18. A device as claimed in claim 15, characterised in that the alignment of the body (20) with the gravitational field is shock-absorbed by electromagnetic means.

19. A device as claimed in claim 15, characterised in that the alignment of the body (20) with the gravitational field is mechanically shock-absorbed by means of friction.

20. A device as claimed in claim 15, characterised in that the alignment of the body (20) with the gravitational field is shock-absorbed by means of shock absorbers based on air pressure or gas pressure.

21. A device as claimed in any of the claims 1 to 20, characterised in that the markers (21) are infrared light-emitting diodes (IREDs).

22. A device as claimed in any of the claims 1 to 21, characterised in that the position sensor (1) is an optoelectronic sensor and comprises at least two cameras (2) the optical axes (14;15;16) of which intersect each other at a point (17).

23. A device as claimed in any of the claims 1 to 22, characterised in that for operating the position detector (12) the computer (8) is equipped with an interface card (11) and the device comprises a System Control Unit (9).

24. A method for correcting X-ray photographs (35) with respect to shortcomings arising from gravity-induced, mechanical deformations of an X-ray apparatus (28) comprising an X-ray source (30) and a receiver (29) by means of the device according to any of the claims 1 to 23,

characterised in that said method comprises the following steps:

a) detecting the direction of the gravity vector (19) within a three-dimensional coordinate system (5;24;26) by means of the position detector (12) and the computer (8).
b) determining the position and orientation of the X-ray apparatus (28) within said coordinate system (5;24;26) by means of the position detector (12) and the computer (8) by measuring the position of the at least three markers (21) fixed on the X-ray apparatus (28) in a non-collinear arrangement;
c) determining the shortcomings of the X-ray photograph (35) from the position and orientation of the X-ray apparatus (28) as determined in step b) by means of the computer (8); and
d) correcting the digital X-ray photograph with respect to the shortcomings determined in step c) by means of the computer (8).

25. A method as claimed in claim 24, characterised in that it further comprises the digitizing of the X-ray photograph (35) and the storing the digitized X-ray photograph (35) in the computer (8).

26. A method as claimed in claim 24 or 25, characterised in that a magneto-optical X-ray photograph (35) is generated by the receiver (29).

27. A method as claimed in claim 26, characterised in that it further comprises the following steps:
e) determining the direction of the normal (31;32) extending perpendicularly to the X-ray photograph (35)

within said coordinate system (5;24;26) from the position and orientation of the X-ray apparatus (28) as determined in step b);

f) determining the shortcomings of the X-ray photograph (35) caused by the Earth's magnetic field from the position and orientation of the X-ray apparatus (28) relative to the gravity vector (19) by means of the computer (8); and

g) correction of the digitized X-ray photograph (35) with respect to said shortcomings by means of the computer (8).

28. A method as claimed in any of the claims 24 to 27, characterised in that the position and orientation of the X-ray source (30) within the coordinate system (5;24;26) is determined by means of the position detector (12) and the computer (8) by measuring the position of at least three markers (21) fixed on the X-ray source (30).

29. A method as claimed in any of the claims 24 to 28, characterised in that the position and orientation of the receiver (29) within the coordinate system (5;24;26) is determined by means of the position detector (12) and the computer (8) by measuring the position of at least three markers (21) fixed on the receiver (29).

30. A method as claimed in claim 29, characterised in that, in addition, shortcomings of the X-ray photograph (35) which are caused by optical deformations of the magneto-optical X-ray photograph (35) occurring in the receiver (29) are determined from the position and orientation of the receiver (29) and that the digitized X-ray photograph (35) is accordingly corrected.

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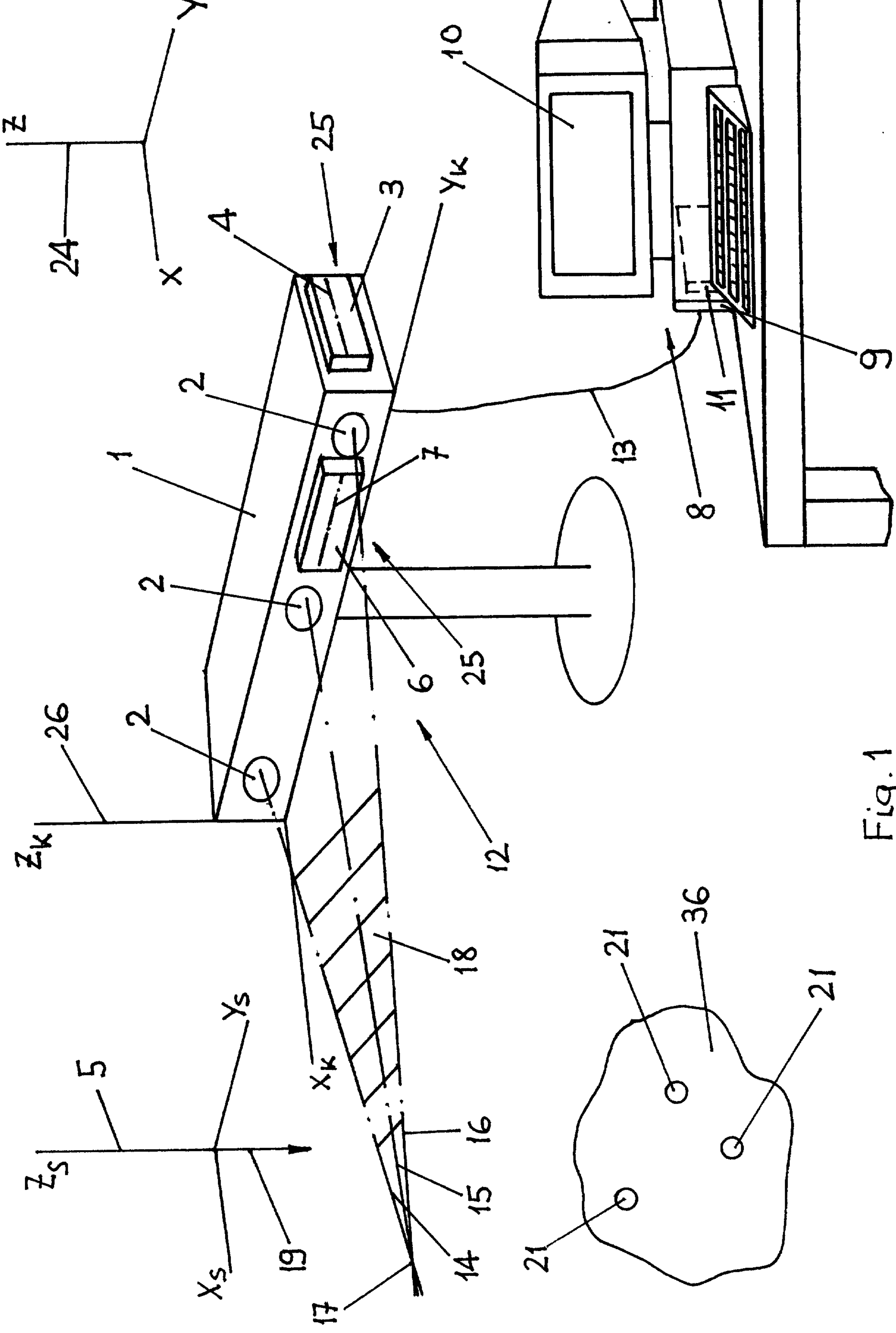
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Fig. 1

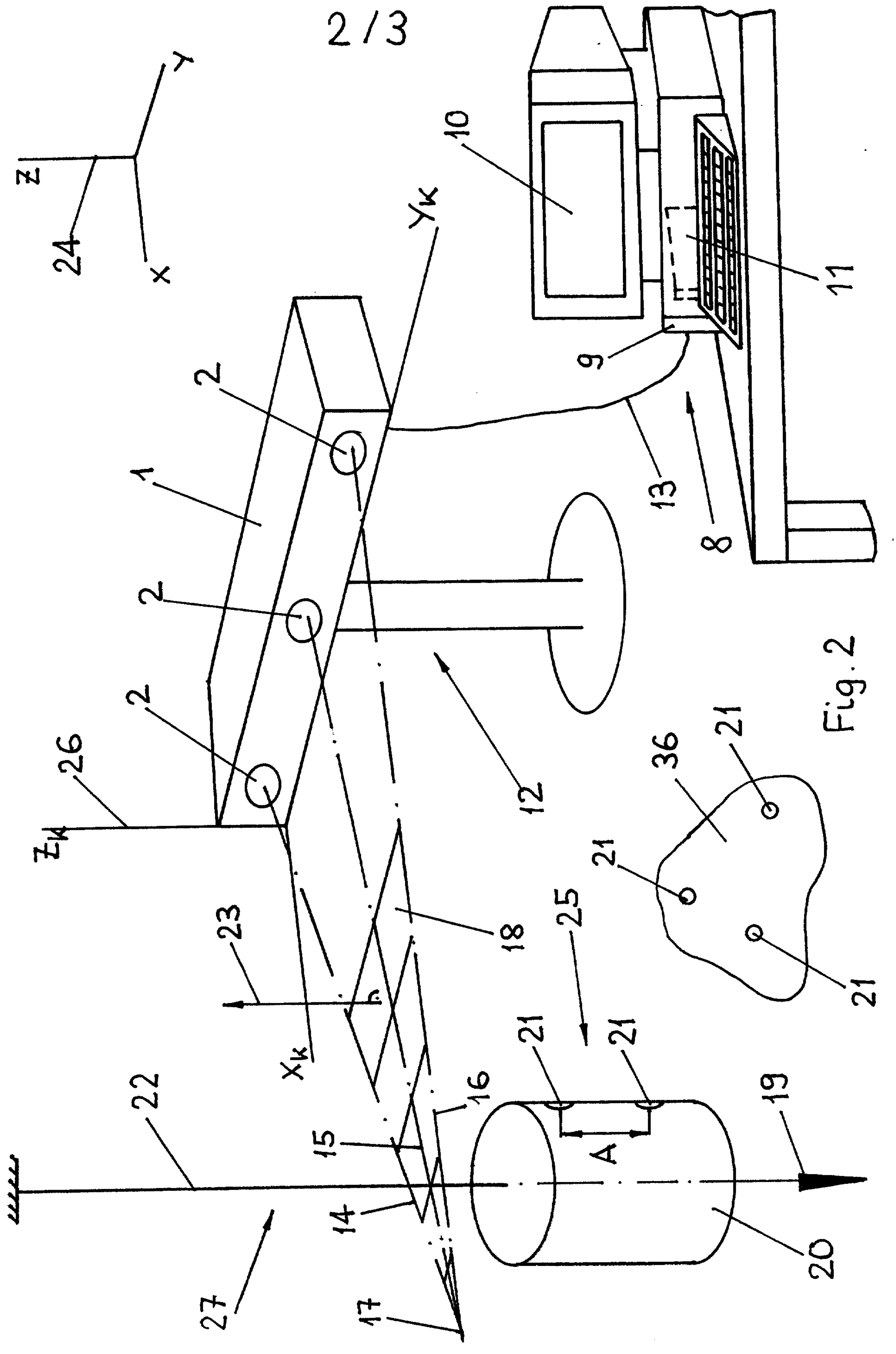
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Fig. 2

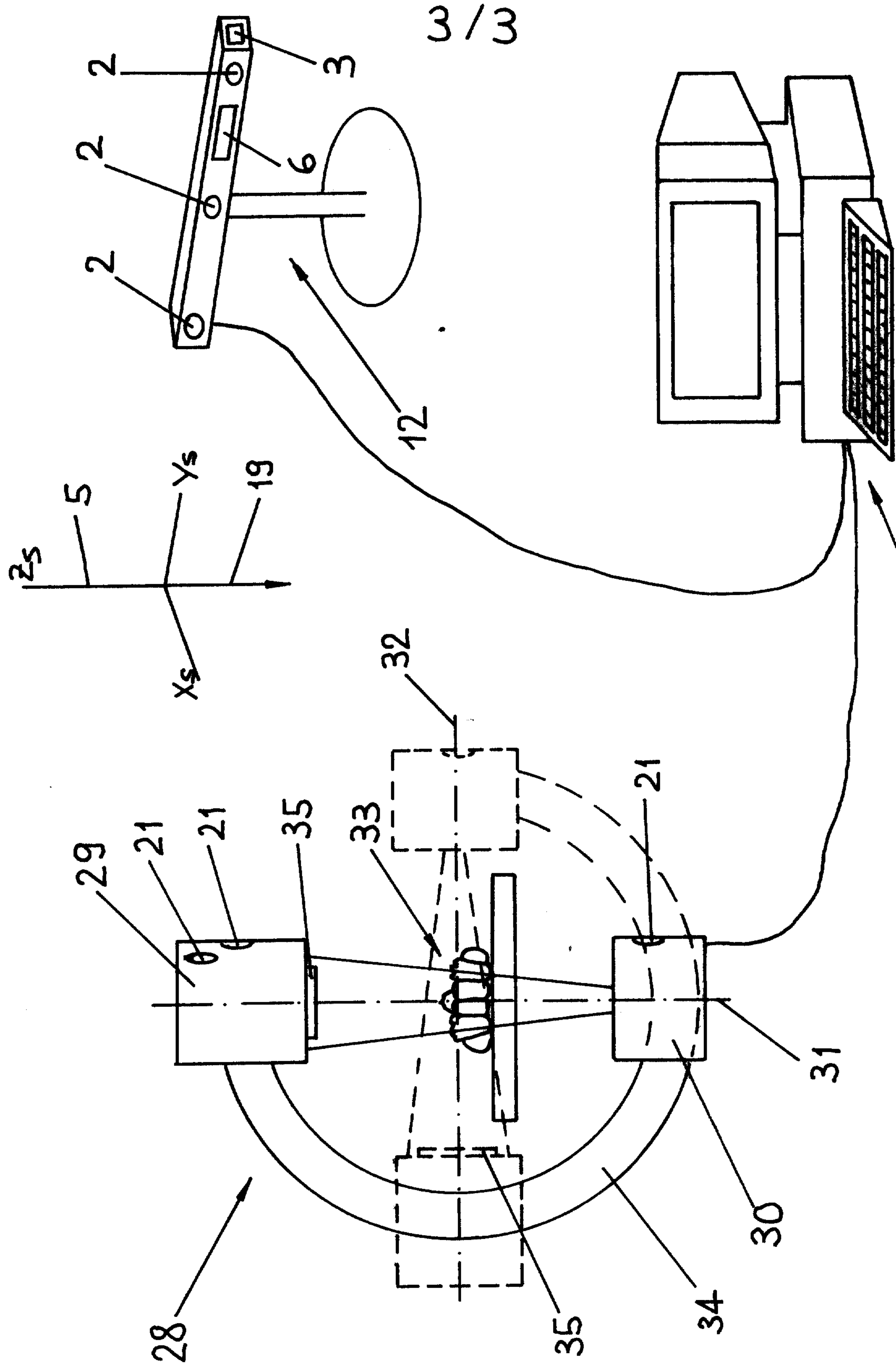
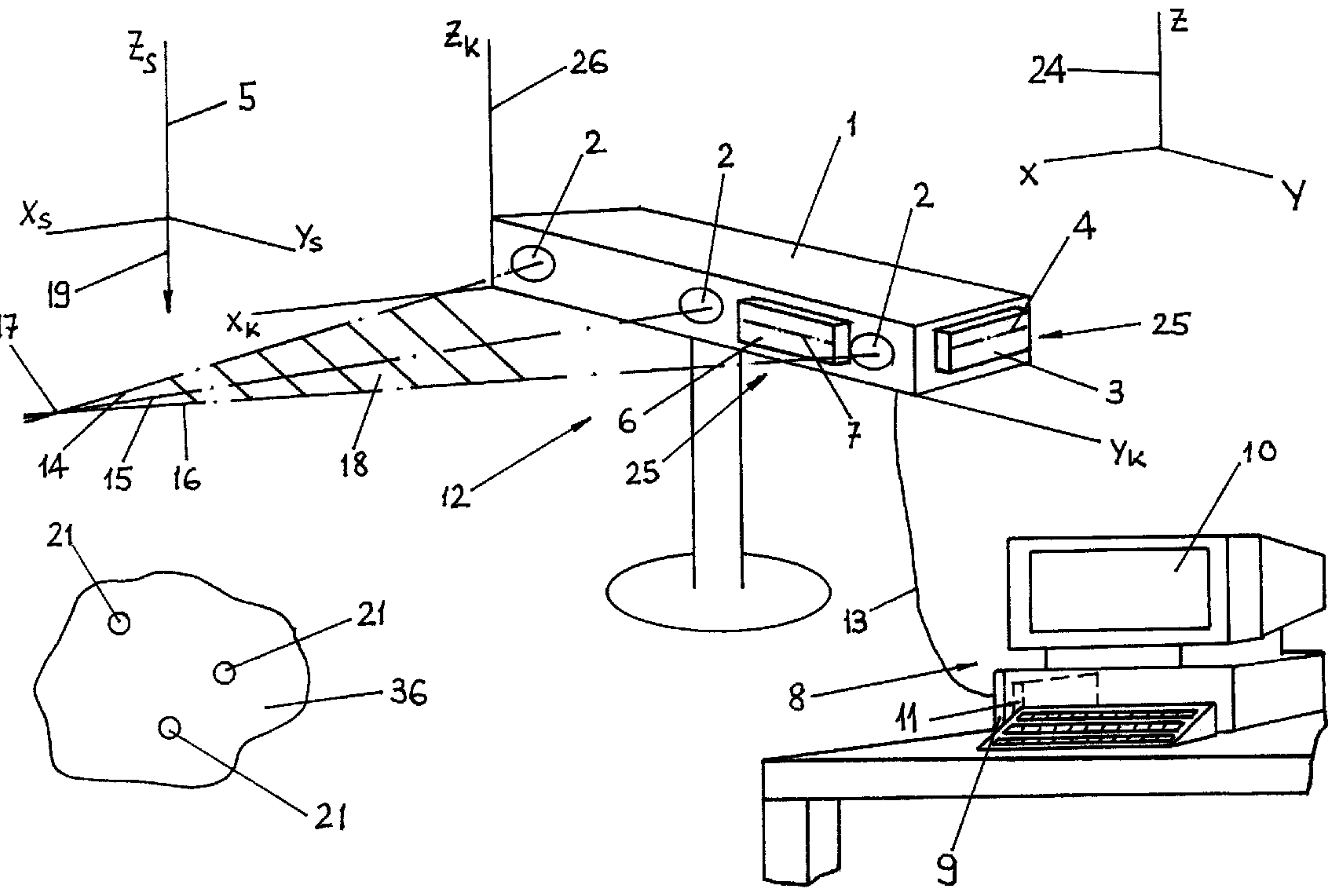


Fig. 3



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