(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 301 019 B1**

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: **10.03.93**

(51) Int. Cl.5: **G01S 5/16**, H04N 7/18, G01B 11/00

(21) Application number: **87902521.1**

(22) Date of filing: **10.04.87**

(86) International application number: **PCT/FI87/00048**

(87) International publication number: **WO 87/06353 (22.10.87 87/23)**

(54) **METHOD FOR THE THREE-DIMENSIONAL SURVEILLANCE OF THE OBJECT SPACE.**

(30) Priority: **11.04.86 FI 861550**

(43) Date of publication of application: **01.02.89 Bulletin 89/05**

(45) Publication of the grant of the patent: **10.03.93 Bulletin 93/10**

(84) Designated Contracting States: **AT BE CH DE FR GB IT LI LU NL SE**

(56) References cited:
EP-A- 132 151
WO-A-85/04245
DE-A- 3 618 480
GB-A- 2 099 255

MANUAL OF PHOTOGRAMMETRY, 4th edition, 1980, American Society of Photogrammetry, Chapter II

(73) Proprietor: **VALTION TEKNILLINEN TUTKIMUSKESKUS**
Vuorimiehentie 5
SF-02150 Espoo 15(FI)

(72) Inventor: **HAGGREN, Henrik**
Vilniementie 12 D 30
SF-02940 Espoo(FI)

(74) Representative: **Patentanwälte Grünecker, Kinkeldey, Stockmair & Partner**
Maximilianstrasse 58
W-8000 München 22 (DE)

EP 0 301 019 B1

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid (Art. 99(1) European patent convention).

Description

The present invention relates to a method for the three-dimensional surveillance of an object space as stated in the preamble of claim 1.

The method of the present invention can be employed for supervising the object space in various conditions and possibly for controlling three-dimensionally the tasks carried out therein. As the three-dimensional variables describing the prevailing conditions, the system supervises various quantities describing the object space and the geometrical shapes of the elements contained therein, as well as their mutual positions and location in the object space and the physical properties of the separate elements of the object.

In the prior art there are known various methods for the three-dimensional supervision of the object space by aid of image acquisition devices. WO-A1 85/04245 describes an optical article dimension measuring system. The dimensions which are to be measured are sectional dimensions i.e., thickness and width of an object such as a slab. There are two line (scan) cameras which are arranged at right angles with each other and by means of which the sectional dimenstions are measured. There is also a third line camera spaced apart from the two cameras which are only used for observing a skew position of the slab. The two cameras are calibrated separately by means of different reference points attached to a claibration frame. Further, the points for one camera are arranged in two strictly parallel and absolutely straight lines in a certain manner.

GB-A 2,099,255 relates to a system in which the position of an object is detected in an enclosure by means of two indicia or identification marks attached to the different sides of an object and two video cameras; the first camera detects the first mark and the second camera detects the second one, both cameras oparate independently. The location of the object is identified on the image plane of each camera, and by aid of these image coordinates of the object, the location of the object within the object space is then calculated. The calculation method is based on the equation of projection of the lens. The focal distance in the optics of both cameras is known. Preliminary to the procedure, there are determined the object space coordinates, in relation to which the angles of the main axis of the camera optics are defined, as well as the distances of the cameras with respect to the origin of the object space coordinates.

According to DE-A-2402204, the location of the object in the object space coordinates is determined by aid of three cameras which are located on the same plane at an angle of 90° with respect to each other. The distances of the cameras from the origin of the object space coordinates are known. The location of the object on the image plane of each camera is expressed, and the deviation of the object, i.e. the angle with respect to the main axis-of each camera (the axes of the object space coordinates) is, defined. The space coordinates of the object are calculated according to certain geometrical equations, wherein the said angles and constants are substituted.

The major drawback in the methods and apparatuses introduced in the above mentioned applications is their inflexibility; they are installed for supervising a given space, whereafter they cannot be shifted. Particularly when several cameras are used for real three-dimensional measuring, the cameras are placed at certain angles (45°, 90°) with respect to each other. This helps to avoid complex calculations when the coordinates are changed. The method and apparatus introduced in the Brittish application is related to the detection of the location of a given object; it is not related to observing changes within the object space. Particularly when the cameras are placed at an angle other than 90° with respect to each other, the chances for errors in the location of the object are drastically increased; the angles of the main axes of the cameras in relation to the axes of the object space coordinates should be determined extremely accurately, as well as the distances of the cameras from the origin of the object space coordinates. This demand for precision in the installation and orientation of the cameras means that the accuracy achieved by the whole system remains relatively modest unless these tasks are carried out with painstaking care. Additional errors are caused by drawbacks in the camera optics. However, high-quality optics and careful assemblage always mean high expenses.

By employing the method of the present invention, among others the problems described in the above applications can in most cases be solved. The invention is characterized by the features enlisted in the characterising part of claim 1.

The measuring method of the invention is a real-time process and the feedback is obtained at the moment of observation. In addition to three-dimensional geometrical information, the method of the present invention can be employed for observing such physical quantities as are necessary for defining the characteristic data of the object space. The object under measurement can be large in size, and it is not necessary to limit the number of pointings. The method does not require that the points of measurement should be activated or signalized. The area of measurement is the whole freely visible area. When required, the measuring system realizing the method can be shifted, easily reset, and it can be automated to a very high degree.

Moreover, the method of the present invention has some properties that are indirectly useful. First of all, along with the present invention, the use of photogrammetry becomes possible in several such measuring tasks requiring a real-time process that so far have been practically impossible. As an example let us mention various assemblage and installation tasks, underwater control and maintenance, the remote control navigation of automatically guided vehicles, and space supervision based on the observance of temperatures. Secondly, in most measuring tasks, an increase in the degree of automation leads to an increase in the efficiency. The performing time of the tasks themselves is shortened, and the need for the costly system expertise is limited mainly to the tasks preceding the set-up of the measuring system and space. Thirdly, along with the measuring system, the manufacturing and assembly work can be integrated into the existing data processing, planning and material administration arrangements of the user. It is also pointed out that the degree of utilization of the user's CAD system is increased when it can be employed both for controlling the measuring system and for comparing the measuring results immediately with the ratings of the plans.

In the following the invention and its background are explained in more detail with reference to the appended drawings, wherein

Figure 1 illustrates a geometrical model on which the method of the invention is based, and

Figure 2 illustrates how the object point is located on the basis of at least two plane projections;

Figure 3 illustrates a measuring system applying the method of the present invention, shown as a block diagram;

Figure 4 illustrates the image processing unit as a block diagram; and

Figure 5 illustrates how the control points are utilized in the determination of the orientation parameters.

The method of the present invention for the three-dimensional supervision of the object space is based on the use of projective, two-dimensional plane observations. When a given detail is observed and located by aid of at least two images, its location in the object space can be determined by three-dimensional coordinates. Let us observe figure 1. There the object point P is projected on the image plane as the point P'. The distance between the object point P and the image point P' is determined through projection in a so-called resection.

The general equation of projection in the case of resection can be expressed as follows:

$$(1)\quad \begin{cases} \dfrac{(x-x_0)}{(z-z_0)} = \dfrac{a_{11}(X-X_0) + a_{21}(Y-Y_0) + a_{31}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)} \\[2ex] \dfrac{(y-y_0)}{(z-z_0)} = \dfrac{a_{12}(X-X_0) + a_{22}(Y-Y_0) + a_{32}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)}, \end{cases}$$

where

x, y, z =	the image coordinates of the point of image;
x_o, y_o, z_o =	the image coordinates of the projection center of the camera;
X, Y, Z =	the object space coordinates of the object point;
X_O, Y_O, Z_O, =	constants representing the projection point O of the camera;
a ...a =	the elements, i.e. the orientation parameters, of the orthogonal rotation matrix of the coordinate change between the camera and object space coordinates.

When we write $z-z_O = c$, i.e. the absolute value of the distance of the projection centre of the camera and the image plane ("the focal distance"), and substitute this clause in the equations (1), we get

$$(2)\quad \begin{cases} x = x_0 + c \cdot \dfrac{a_{11}(X-X_0) + a_{21}(Y-Y_0) + a_{31}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)} \\[2ex] y = y_0 + c \cdot \dfrac{a_{12}(X-X_0) + a_{22}(Y-Y_0) + a_{32}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)} \end{cases}$$

The orientation parameters a_{11} ...a_{33} include the unknown quantities κ, ζ, and ω, which are the angles of orientation between the object space coordinates and camera coordinates. Now the solving of the unknown quantities of each image entails at least the determination of the following unknowns:

$$(3)\quad \begin{cases} \kappa, \varphi, \omega \\ x_0, y_0, z_0 = c \\ X_0, Y_0, Z_0 \end{cases}$$

The total number of the unknowns is 9. From each predetermined control point we get two equations of observation (2), and therefore in order to solve the unknowns in one single image we need at least five control points where X, Y and Z are known. It is also pointed out that the control points must be independent of each other in such a fashion that they are not located on the same plane, in order to obtain an unambiguous solution.

The rays of projection are never absolutely straight, but they are diffracted in the medium agent (air, lens, water etc.). These diffraction errors can be taken into account by enlarging the mathematical model by aid of so-called auxiliary parameters. If these auxiliary parameters can be treated as systematical sources of error, they can be solved image by image. The most commonly used models for auxiliary parameters correct the lens distortion errors and errors in the image coordinates.

The use of the enlarged model must always be considered separately for each case. Practice has shown that justified grounds for use exist when the influence of the auxiliary parameter is at least 1/5 of the measuring accuracy of the image coordinate. The use of auxiliary parameters also requires respective measuring accuracy as regards the object space coordinates of the control points. Each auxiliary parameter in part requires new control points and equations of observation (2).

The reversed projection, figure 2, i.e. from the image into the object, is not unambiguous with respect to the object point P. At least two plane projections are used in locating the object point. The location is carried out, by aid of the projection lines O_iP_i (i = 1, 2, 3,...) reconstructed from the projective measurements, in a so-called intersection.

In the intersection, the reversed forms of the equations of projection (1) are employed. Because by defining the object points there must be in each case defined three coordinate values, the object point must always be observed with at least two images i and j.

The general equation of projection can be presented in the following form:

$$(4)\quad \begin{cases} \dfrac{X-X_0}{Z-Z_0} = \dfrac{a_{11}(x-x_0) + a_{12}(y-y_0) + a_{13}(z-z_0)}{a_{31}(x-x_0) + a_{32}(y-y_0) + a_{33}(z-z_0)} \\[2ex] \dfrac{Y-Y_0}{Z-Z_0} = \dfrac{a_{21}(x-x_0) + a_{22}(y-y_0) + a_{23}(z-z_0)}{a_{31}(x-x_0) + a_{32}(y-y_0) + a_{33}(z-z_0)}, \end{cases}$$

where

x and y are the observed camera coordinates of the new point in images i and j, and

X, Y, Z are the object space coordinates of the new point to be calculated.

The rest of the quantities, i.e. the orientation parameters a_{11} ...a_{33}, are solved image by image in connection with the resection.

By substituting the observations and the solved unknown quantities in the equations (4) we obtain

$$(5)\quad \begin{cases} X-X_{0i} = (Z-Z_{0i}) \cdot I_{i1} \\ Y-Y_{0i} = (Z-Z_{0i}) \cdot I_{i2} \\ X-X_{0j} = (Z-Z_{0j}) \cdot I_{j1} \\ Y-Y_{0j} = (Z-Z_{0j}) \cdot I_{j2} \end{cases}$$

In the equations, the right-hand side of the equations (4) is marked imagewise with the following constants: I_{i1}, I_{i2}, I_{j1} and I_{j2}. Thereafter the object space coordinates X, Y and Z can be solved from the equations (5) stage by stage for instance as follows:

a) $X = X_{oi} + (Z-Z_{oi}) \cdot I_{i1} = X_{oj} + (Z-Z_{0j}) \cdot I_{j1}$

b) $X_{oi} + Z \cdot I_{i1} - Z_{oi} \cdot I_{i1} = X_{oj} + Z \cdot I_{j1} - Z_{oj} \cdot I_{j1}$

c)

$$Z = \frac{X_{oj} - X_{oi} - Z_{oj} \cdot I_{j1} + Z_{oi} \cdot I_{i1}}{I_{i1} - I_{j1}},$$

whereafter Z is solved, and the process is continued for instance as follows:

d) $X = (Z-Z_{0i})\, I_{i1} - X_{0i}$ and

e) $Y = (Z-Z_{0i})\, I_{j2} - Y_{0i}$,

whereafter X and Y are also solved.

If the model enlarged with auxiliary parameters is used, then before solving the object space coordinates X, Y and Z, in the image observations x_i, y_i; x_j and y_j there are made the corresponding corrections as in connection with the resection process.

In the method of the invention the image acquisition devices, such as video cameras, are installed at an angle with respect to each other in order to observe the desired object space, and in this object space there are arranged control points; the object coordinates X_k, Y_k, Z_k; k = 1, 2, 3... of the said control points are measured, and the projectionwise image coordinates x_{ki} , y_{ki} ; x_{kj}, y_{kj} are determined on the corresponding image acquisition devices i, j, whereafter the control points can be removed from the object space; on the basis of the image and object space coordinate values the orientation parameters a_{11} ...a_{33} of projective resection are calculated, whereafter the unknown object space coordinates X, Y, Z of the observed object points can be solved in a real-time process by aid of the image coordinates x_i, y_i; x_j, y_j observed on the image acquisition devices by utilizing the method of projective intersection.

It is pointed out that in the method of the present invention it is not necessary to determine the image acquisition devices nor their location before carrying out the projection, nor the angles of orientation between the object and camera coordinates nor the focal distances of the cameras. Moreover, the employed control points are generally removed from the object space immediately after their location is determined and/or after the orientation parameters are calculated, so that they do not by any means disturb the supervision of the object space. When the orientation parameters of the image acquisition devices are determined, each sufficiently changed object or an object otherwise distinctive in the background, which object is located within the common field of vision of the cameras, i.e. within the object space, can be located.

In the method of the invention, the once determined orientation parameters a_{11} ...a_{33} are continuously used when solving the unknown object space coordinates X, Y, Z of the object points by aid of the image coordinates x, y, observed on the image acquisition devices, as long as the said devices are positioned at a solid angle with respect to each other and register the object space. When following this procedure, the determination of the coordinates of the object points is considerably speeded up; in the determination procedure, the stage which takes the largest period of time is the calculation of the orientation parameters.

One preferred example of the application of the method of the invention is an application where the image acquisition devices are coupled at given intervals from each other in a stationary manner and at solid angles with respect to each other, so that their common field of vision, i.e. the object space, is defined and this space can be continuously observed. This means that the image acquisition devices, together with their object space, form a closed system. It is not dependent on external factors. This being the case, the projection system can be constructed on a movable platform (car, train carriage, ship, etc.), and it can supervise its surroundings outside this movable platform within the range of the common field of vision of the image acquisition devices. The orientation parameters can be determined beforehand in the desired conditions, whereafter the measuring system can be employed in on-site work.

The general equations of projection in resection (1) and in intersection (4) can be presented in general form as the following transformation matrix:

$$(6)\quad \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}_{ij} = \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix}_{ij} + \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix}_{ij} \cdot \begin{vmatrix} x \\ y \\ c \end{vmatrix}_{ij}$$

where

$X_i, Y_i, Z_i\ X_j, Y_j, Z_j$ =	the object space coordinates, i.e. the coordinates of the object points in the XYZ coordinates of the object space;
$X_{oi}, Y_{oi}, Z_{oi}\ X_{oj}, Y_{oj}, Z_{oj}$ =	the constants representing the projection point O_i, O_j of each image acquisition device i, j;
a_{11} ...a_{33} =	the projective orientation parameters of the images;
c_i, c_j =	the constants of the image acquisition devices;
$x_i, y_i\ x_j, y_j$	= the coordinates of the image points on the image planes of each image acquisition device i, j;
i, j =	the image acquisition devices i and j.

On the basis of this transformation matrix, all required quantities can be solved as was described above in connection with the equations (1) and (4).

Figure 3 illustrates a measuring system where the method of the invention is applied. The object space 1 to be observed is located in the three-dimensional axis of coordinates XYZ. The object is formed of the observable points p (X, Y, Z). The measurement is carried out by registering the object space by means of the image acquisition devices 2 and 3, such as video cameras, located at given intervals from each other. The image acquisition devices are connected to a data processing system 4. The data processing system 4 comprises for instance the registering unit 5, the image processing unit 6, the logic unit 7 and the functional unit 8. The registering unit 5 controls the image acquisition and the possible signalization of the measuring points, and transmits the images forward. It is provided for instance with the necessary timers and A/D converters. In the image processing unit 6, the images are interpreted: the common points of both images are searched and the image coordinates P'(x, y) are calculated, and possibly the characteristic data of the object point is interpreted; the object coordinates of the object point P(X, Y, Z) are calculated, intermediate results are stored, and possibly some timewise comparisons are carried out in between the results. The final result is fed into the logic unit 7, where the decisions for actions are made. Into the decision-making process of the logic unit 7 there can also be fed other space data in addition to the space data 13 acquired during the survey. The functional unit 8 takes care of the necessary actions 11 directed to the object space, the necessary actions 12 directed to the image acquisition space and other actions 14, which include for example guidance of the operations in the object space.

In figure 4 there is illustrated a preferred embodiment of the image processing unit 6. Through the input interface A, B of the unit, a digitized video signal is fed in from both of the image acquisition devices 2, 3 into the first image memories 15a, 15b. The first and the second image memory 15a, 15b and 16a, 16b are connected to the identifier 17a, 17b of changed image areas, wherein the treshold value is also set. The identifier 17a, 17b is coupled to the determination circuit 18a, 18b of the image coordinates x, y of the transformation point. When desired, the contents of the second image memory 16a, 16b can be renewed from the image acquisition device 2, 3, through the complementary circuit 19a, 19b of the second image memory.

The digitized image signal is stored into the first image memory 15a, 15b and further into the identifier 17a, 17b of changed image areas, whereinto the previously sent image information from the second image memory 16a, 16b, or corresponding information, is also stored. When a given image area is identified as changed in the identifier 17a, 17b, it is checked whether the changed image information, such as the intensity of the image area, surpasses the preset treshold value, and if the answer is positive, the coordinates x, y of the changed point are calculated by aid of the determination circuit 18a, 18b.

When the point of change x, y is determined on the image plane of each image acquisition device 2, 3, the said image coordinates are fed into the calculation unit 20 or corresponding data processing unit. The equation (4) is solved with respect to the object space coordinates, whereafter the calculated coordinates X, Y, Z of the object point are fed into the logic unit 8 through the output interface C.

Before the measurement proper, the orientation parameters must be calculated as was explained above. This is carried out by aid of the determination of the control points, which procedure in figure 3 is illustrated by the block 21. The orientation parameters are calculated in the calculation unit 20 for instance on the basis of the equation (1) or (2) or on the basis of the matrix (6).

The measuring of the control points is illustrated in figure 5. The image acquisition devices and their orientations are represented by the arrows 22, 23. In the object space coordinates XYZ, there is the object 24 to be observed, which together with its surroundings is included in the field of vision, i.e. the object space, of both of the image acquisition devices. In this case the control points 25 are marked as clearly distinguishable from the background on different sides of the object space most advantageously so that the object under observation is included in the space outlined by the control points. In figure 5, there are marked nine control points 25. The image coordinates x_k, y_k of the points are measured from the images by means of the measuring system of the apparatus itself. The object space coordinates X_k, Y_k, Z_k; $k = 1, 2...9$ are measured for example geodetically by employing an electronic tachymeter, and the coordinate values are fed, for instance by aid of a keyboard, into the calculation unit 20. Thereafter, by aid of the calculation unit and on the basis of the transformation matrix (6), there are calculated the orientation parameters a_{11} ...a_{33}. The object space coordinates of the control points can also be fed directly into the calculation unit from the tachymeter coupled to the apparatus.

When the orientation parameters are calculated by aid of the control points, the object space is defined and the control points, i.e. their marks or traces, can be removed. Thereafter they do not in any way limit the measuring of the object or movements in the object space. It is naturally clear that the above described measuring of the control points can be carried out in an empty object space, i.e. without any specific object under measurement.

When the apparatus has "learned" these control points, it is capable of determining all other points in the object space seen by both of the cameras. By indicating these unknown points, the system calculates coordinates for them. In order to indicate the points to be measured, there can be employed measuring aid marks, specific light sources or a spot of light scanning the object and/or the whole of the object space. Particular signalization methods are not needed in all cases, but instead of them there can be constructed systems which automatically search the object for interesting points of measurement. Movable objects are easily located as such.

It is particularly emphasized that the image acquisition device is in operation such that in addition to visible light, it is capable of registering other electromagnetic radiation as well. In the interpretation, the object point located three-dimensionally on the basis of radiation intensities can also be provided with the local characteristic information of the said object point. The use of the method is not limited by the image resolution, but this is always related to the required accuracy of measurement.

The structure of the measuring system applying the method of the invention can in various modifications and surroundings be remarkably different from those illustrated in figures 3 and 4. The structure is also affected by the other data processing systems employed by the user, by the required degree of automation and the nature of the operations 11, 12 and 14.

Claims

1. A method for the three-dimensional surveillance of an object space including object points in this object space, which method comprises the steps of

a) arranging at least two image acquisition devices (i,j) to register the said object space;

b) positioning said image acquisition devices (i,j) at an angle with respect to each other in order to observe said object space;

c) digitizing the images received by the image acquisition devices (i,j);

d) projecting object points on to the image planes of the image acquisition devices (i,j) to establish their corresponding image points;

e) determining the image coordinates x_i, y_j of said image points from their respective image acquisition devices (i,j);
f) calculating in a real time process the space coordinates X, Y and Z of said object points in the three-dimensional object space on the basis of said image point coordinates x_i, y_i and x_j, y_j, by making use of equations satisfied by straight lines connecting an object point and the corresponding image point on the image plane of the acquisition devices (i,j);

characterised in that
g) the coordinates X, Y, Z are calculated by making use of at least three of equations:

$$\frac{X - X_{oi}}{Z - Z_{oi}} = \frac{a_{11i} x_i + a_{12i} y_i + a_{13i} c_i}{a_{31i} x_i + a_{32i} y_i + a_{33i} c_i}$$

$$\frac{Y - X_{oi}}{Z - Z_{oi}} = \frac{a_{21i} x_i + a_{22i} y_i + a_{23i} c_i}{a_{31i} x_i + a_{32i} y_i + a_{33i} c_i}$$

$$\frac{X - X_{oj}}{Z - Z_{oi}} = \frac{a_{11j} x_j + a_{12j} y_j + a_{13j} c_j}{a_{31j} x_j + a_{32j} y_j + a_{33j} c_j}$$

$$\frac{Y - Y_{oj}}{Z - Z_{oj}} = \frac{a_{21j} x_j + a_{22j} y_j + a_{23j} c_j}{a_{31j} x_j + a_{32j} y_j + a_{33j} c_j}$$

where

X,Y,Z represent the coordinates of an object point to be determined;

X_{oi},Y_{oi},Z_{oi} represent the coordinates of the projection point of the acquisition device (i) in the coordinate system corresponding to the coordinates X, Y, Z;

X_{oj},Y_{oj},Z_{oj} represent the coordinates of the projection point of the acquisition device (j) in the coordinate system corresponding to the coordinates X, Y, Z, said coordinates being constant;

x_i,y_i are coordinates of an image point corresponding to an object point having the coordinates X, Y, Z to be determined, said coordinates of said image point relating to a coordinate system associated with the acquisition device i;

C_i represents the Z_i coordinate of said image point having the coordinates x_i, y_i; this value being constant for all image points;

x_j,y_j are coordinates of an image point corresponding to an object point having the coordinates X, Y, Z to be determined, said coordinates of said image point relate to a coordinate system associated with the acquisition device j;

C_j represents the Z_j coordinate of said image point having the coordinates x_j, y_j; this value being constant for all image points;

$a_{11i}...a_{33i}$ are parameters representing the orientation of the coordinate system associated with the acquisition device i with respect to the coordinate system corresponding to the coordinates X, Y, Z; and

$a_{11j}...a_{33j}$ are parameters representing the orientation of the coordinate system associated with the acquisition device j with respect to the coordinate system corresponding to the coordinates X, Y, Z,

and the method further comprises the steps of;
h) arranging k calibration points in said object space so that they are not located in the same plane; where k is at least five;
i) measuring the object space coordinates X_k, Y_k, Z_k (k = 1, 2, 3...) of said calibration points;
j) projecting said calibration points on to the image planes of each said image acquisition device (i,j) to establish their corresponding image calibration points;
k) determining the image point coordinates x_{ki}, y_{ki}, and x_{kj}, y_{kj} of said image calibration points from their respective image acquisition devices (i,j) whereafter said calibration points are removed from the object space;
l) calculating the orientation parameters ($a_{11}...a_{33}$) on the basis of the image coordinate and space coordinate values of the calibration points using at least three of equations defined at step g;
m) employing the said determined orientation parameters ($a_{11}...a_{33}$) when calculating according to step g) the unknown space coordinates (X,Y,Z) of the object points on the basis of the determined image point coordinates, x_i,y_i and x_j,y_j, observed by the image acquisition devices (i,j), as long as said devices are positioned at a fixed angle with respect to each other and are registering said object space.

2. A method according to claim 1, **characterised in that** the method comprises the step of coupling image acquisition devices (i,j) at given distances to each other in a stationary manner and at a fixed angle with respect to each other, so that their common field of vision , i.e. the object space, is determined and this space can be continuously observed.

3. A method according to claim 1, **characterised in that** the method comprises the step of choosing the calibration points so that they cover the three-dimensional space registered by the image acquisition devices (i,j).

4. A method according to claim 1, **characterised in that** the method comprises the step of arranging the number of the calibration points more than 5, i.e., more than the smallest number required in the calculation of the orientation parameters.

5. A method according to claim 1, **characterised in that** the method comprises the step of signalizing the object points to be measured by aid of measuring aid marks.

6. A method according to claim 5, **characterised in that** the method comprises the step of step of signalizing the object points to be measured by aid of spots of light arranged to scan the object space.

Patentansprüche

1. Ein Verfahren zur dreidimensionalen Überwachung eines Objetraums, welcher Objektpunkte in diesem Objetraum enthält, wobei das Verfahren die Schritte umfaßt:
a) Vorsehen von wenigstens zwei Bildaufnahmegeräten (i, j) um den Objektraum aufzunehmen;
b) Anordnen der Bildaufnahmegräte (i, j) unter einem Winkel in Bezug zueinander, um den Objektraum zu beobachten;
c) Digitalisieren der durch die Bildaufnahmegeräte (i, j) empfangenen Bilder;
d) Projizieren von Objektpunkten auf die Bildebenen der Bildaufnahmegeräte (i, j), um ihre entsprechenden Bildpunkte zu erzeugen;
e) Bestimmen der Bildkoordinaten x_i, y_i und x_j, y_j der Bildpunkte von ihren jeweiligen Bildaufnahmegeräten (i, j);
f) Berechnen der Raumkoordinaten X, Y und Z der Objektpunkte in dem dreidimensionalen Objektraum auf der Basis der Bildpunktkoordinaten x_i, y_i und x_j, y_j in einem Echtzeitverfahren durch Verwendung von Gleichungen, welche durch gerade Linien erfüllt werden, welche einen Objektpunkt

und einen entsprechenden Bildpunkt auf der Bildebene der zwei Aufnahmegeräte (i, j) verbinden,

dadurch gekennzeichnet, daß

g) die Koordinaten x, Y, Z berechnet werden, indem von wenigstens drei von Gleichungen

$$\frac{X - X_{oi}}{Z - Z_{oi}} = \frac{a_{11i} x_i + a_{12i} y_i + a_{13i} c_i}{a_{31i} x_i + a_{32i} y_i + a_{33i} c_i}$$

$$\frac{Y - X_{oi}}{Z - Z_{oi}} = \frac{a_{21i} X_i + a_{22i} Y_i + a_{23i} C_i}{a_{31i} X_i + a_{32i} Y_i + a_{33i} C_i}$$

$$\frac{X - X_{oj}}{Z - Z_{oi}} = \frac{a_{11j} X_j + a_{12j} Y_j + a_{13j} C_j}{a_{31j} X_j + a_{32j} Y_i + a_{33j} C_j}$$

$$\frac{Y - Y_{oj}}{Z - Z_{oj}} = \frac{a_{21j} X_j + a_{22j} y_j + a_{23j} C_j}{a_{31j} x_j + a_{32j} y_j + a_{33j} C_j}$$

Gebrauch gemacht wird, worin

X, Y, Z die Koordinaten eines zu bestimmenden Objektpunktes repräsentieren;

X_{oi}, Y_{oi}, Z_{oi} die Koordinaten des Projektionspunktes des Aufnahmegerätes (i) in dem den Koordinaten X, Y, Z entsprechenden Koordinatensystem repräsentieren;

X_{oj}, Y_{oj}, Z_{oj} die Koordinaten des Projektionspunktes des Aufnahmegerätes (j) in dem den Koordinaten X, Y, Z entsprechenden Koordinatensystem respräsentieren, wobei diese Koordinaten konstant sind;

x_i, y_i Koordinaten eines Bildpunktes, welcher einem zu bestimmenden Objektpunkt mit den Koordinaten X, Y, Z entspricht, sind, wobei die Koordinaten des Bildpunktes sich auf ein Koordinatensystem beziehen, welches mit dem Aufnahmegerät (i) verbunden ist;

C_i die Z_i-Koordinate des Bildpunktes mit den Koordinaten x_i, y_i repräsentiert, wobei dieser Wert für alle Bildpunkte konstant ist;

x_j, y_j Koordinaten eines Bildpunktes, welcher einem zu bestimmenden Objektpunkt mit den Koordinaten X, Y, Z entspricht, repräsentieren, wobei die Koordinaten des Bildpunktes sich auf ein Koordinatensystem beziehen, welches dem Aufnahmegerät (j) zugeordnet ist;

C_j die Z_j-Koordinate des Bildpunktes mit den Koordinaten x_j, y_j repräsentiert, wobei dieser Wert für alle Bildpunkte konstant ist;

a_{11i} ... a_{33i} Parameter sind, welche die Orientierung des dem Aufnahmegerät (i) zugeordneten Koordinatensystems in bezug auf das den Koordinaten X, Y, Z entsprechende Koordinatensystem repräsentieren; und

a_{11j} ... a_{33j} Parameter sind, welche die Orientierung des dem Aufnahmegerät (j) zugeordneten Koordinatensystems in bezug auf das den Koordinaten X, Y, Z entsprechende Koordinatensystem repräsentieren,

und das Verfahren ferner die Schritte umfaßt:
h) Vorsehen von k Kalibrierungspunkten in dem Objektraum derart, daß sie nicht in der gleichen Ebene angeordnet sind, wobei k wenigstens fünf beträgt;
i) Messen der Objektraumkoordinaten X_k, Y_k, Z_k (k = 1, 2, 3 ...) der Kalibrierungspunkte;
j) Projizieren der Kalibrierungspunkte auf die Bildebenen in jedem Aufnahmegerät (i, j), um ihre entsprechenden Bildkalibrierungspunkte zu erzeugen;
k) Bestimmen der Bildpunktkoordinaten x_{ki}, y_{ki} und x_{kj}, y_{kj} der Bildkalibrierungspunkte von ihren jeweiligen Bildaufnahmegeräten (i, j), wonach die Kalibrierungspunkte aus dem Objektraum entfernt werden;
l) Berechnen der Orientierungsparameter (a_{11} ... a_{33}) auf der Basis der Bildkoordinaten und Raumkoordinatenwerte der Kalibrierungspunkte unter Verwendung von wenigstens drei von im Schritt g) definierten Gleichungen; und
m) Verwenden der bestimmten Orientierungsparameter (a_{11} ... a_{33}) beim Berechnen der unbekannten Raumkoordinaten (X, Y, Z) der Objektpunkte entsprechend Schritt g) auf der Basis der bestimmten Bildpunktkoordinaten, x_i, y_i und x_j, y_j, die durch die Bildaufnahmegeräte (i, j) beobachtet werden, solange die Geräte unter einem festen Winkel in Bezug zueinander angeordnet sind und den Objektraum aufnehmen.

2. Ein Verfahren nach Anspruch 1, **dadurch gekennzeichnet,** daß das Verfahren den Schritt der Kopplung von Bildaufnahmegeräten (i, j) in einem gegebenen Abstand zueinander in einer stationären Weise und unter einem festen Winkel in Bezug zueinander, so daß ihr gemeinsames Gesichtsfeld, d.h. der Objektraum, festgelegt ist, und dieser Raum kontinuierlich beobachtet werden kann, umfaßt.

3. Ein Verfahren nach Anspruch 1, **dadurch gekennzeichnet,** daß das Verfahren den Schritt der Auswahl der Kalibrierungspunkte derart umfaßt, daß sie den durch die Bildaufnahmegeräte (i, j) aufgenommenen dreidimensionalen Objektraum abdecken.

4. Ein Verfahren nach Anspruch 1, **dadurch gekennzeichnet,** daß bei dem Verfahren die Zahl der Kalibrierungspunkte > 5 vorgesehen wird, d.h., größer als die kleinste für die Berechnung der Orientierungsparameter erforderliche Anzahl.

5. Ein Verfahren nach Anspruch 1, **dadurch gekennzeichnet,** daß Verfahren den Schritt der Hervorhebung der zu messenden Objektpunkte mit Hilfe von Meßhilfsmarken umfaßt.

6. Ein Verfahren nach Anspruch 5, **dadurch gekennzeichnet,** daß das Verfahren den Schritt der Hervorhebung der zu messenden Objektpunkte mit Hilfe von zur Abtastung des Objektraums vorgesehenen Lichtspots umfaßt.

Revendications

1. Procédé permettant la surveillance tridimensionnelle d'un espace objet contenant des points objet situés dans cet espace objet, ce procédé comprenant les étapes consistant :
a) à agencer au mains deux dispositifs d'acquisition d'image (i, j) de façon qu'ils enregistrent l'espace objet,
b) à positionner les dispositifs d'acquisition d'image (i, j) de façon qu'ils fassent un certain angle entre eux en vue d'observer l'espace objet,
c) à numériser les images reçues par les dispositifs d'acquisition d'image (i, j),
d) à projeter des points objet sur les plans image des dispositifs d'acquisition d'image (i, j) de façon à former leurs points image correspondants,
e) à déterminer les coordonnées d'image x_i, y_j desdits points image à partir de leurs dispositifs d'acquisition d'image (i, j) respectifs,
f) à calculer, suivant un processus en temps réel, les coordonnées spatiales X, Y et Z desdits points objet dans l'espace objet tridimensionnel sur la base desdites coordonnées de point image x_i, y_i et x_j, y_j, en utilisant des équations qui sont satisfaites par des lignes droites reliant un point objet et le

point image correspondant situé sur le plan image des dispositifs d'acquisition (i, j),

caractérise en ce que :

g) les coordonnées X, Y, Z sont calculées en utilisant au moins trois des équations :

$$[X - X_{oi}]/[Z - Z_{oi}] = [a_{11i}x_i + a_{12i}y_i + a_{13i}c_i]/[a_{31i}x_i + a_{32i}y_i + a_{33i}c_i]$$
$$[Y - X_{oi}]/[Z - Z_{oi}] = [a_{21i}x_i + a_{22i}y_i + a_{23i}c_i]/[a_{31i}x_i + a_{32i}y_i + a_{33i}c_i]$$
$$[X - X_{oj}]/[Z - Z_{oj}] = [a_{11j}x_j + a_{12j}y_j + a_{13j}c_j]/[a_{31j}x_j + a_{32j}y_j + a_{33j}c_j]$$
$$[Y - Y_{oj}]/[Z - Z_{oj}] = [a_{21j}x_j + a_{22j}y_j + a_{23j}c_j]/[a_{31j}x_j + a_{32j}y_j + a_{33j}c_j]$$

dans lesquelles

X, Y, Z représentent les coordonnées d'un point objet à déterminer,

X_{oi}, Y_{oi}, Z_{oi} représentent les coordonnées du point de projection du dispositif d'acquisition (i) dans le système de coordonnées correspondant aux coordonnées X, Y, Z,

X_{oj}, Y_{oj}, Z_{oj}, représentent les coordonnées du point de projection du dispositif d'acquisition (j) dans le système de coordonnées correspondant aux coordonnées X, Y, Z, lesdites coordonnées étant constantes,

x_i, y_i sont des coordonnées d'un point image correspondant à un point objet ayant les coordonnées X, Y, Z à déterminer, lesdites coordonnées dudit point image étant liées à un système de coordonnées associé au dispositif d'acquisition i,

c_i représente la coordonnée z_i dudit point image ayant les coordonnées x_i, y_i, cette valeur étant constante pour tous les points image,

x_j, y_j sont des coordonnées d'un point image correspondant à un point objet ayant les coordonnées X, Y, Z à déterminer, lesdites coordonnées dudit point image étant liées à un système de coordonnées associé au dispositif d'acquisition j,

c_j représente les coordonnées z_j dudit point image ayant les coordonnées X_j, Y_j, cette valeur étant constante pour tout point image,

a_{11i} ... a_{33i} sont des paramètres représentant l'orientation du système de coordonnées associé au dispositif d'acquisition i vis-à-vis du système de coordonnées correspondant aux coordonnées X, Y, Z et

a_{11j} ... a_{33j} sont des paramètres représentant l'orientation du système de coordonnées associé au dispositif d'acquisition j vis-à-vis du système de coordonnées correspondant aux coordonnées X, Y, Z,

le procédé consistant en outre :

h) à disposer des points d'étalonnage k dans l'espace objet de façon qu'ils ne soient pas situés dans le même plan, k étant au moins égal à cinq,

i) à mesurer les coordonnées X_k, Y_k, Z_k (k = 1, 2, 3 ...) des points d'étalonnage dans l'espace objet,

j) à projeter les points d'étalonnage sur les plans image de chaque dispositif d'acquisition d'image (i, j) de façon à établir leurs points d'étalonnage image correspondants,

k) à déterminer les coordonnées de point image x_{ki}, y_{ki} et x_{kj}, y_{kj} des points d'étalonnage image à partir de leur dispositifs d'acquisition d'image (i, j) respectifs, à la suite de quoi on retire de l'espace objet les points d'étalonnage,

l) à calculer les paramètres d'orientation (a_{11} ... a_{33}) sur la base des valeurs de coordonnée d'image et de coordonnée d'espace des points d'étalonnage, en utilisant au moins trois des équations définies à l'étape g,

m) à utiliser les paramètres d'orientation (a_{11} ... a_{33}) déterminés, lorsqu'on calcule, conformément à l'étape g), les coordonnées d'espace (X, Y, X) inconnues des points objet sur la base des coordonnées de point image x_i, y_i et x_j, y_j déterminées, qui sont observées par les dispositifs d'acquisition d'image (i, j), aussi longtemps que lesdits dispositifs sont positionnés en faisant un angle fixe entre eux et qu'ils enregistrent l'espace objet.

2. Procédé suivant la revendication 1, caractérisé en ce qu'il comprend l'étape consistant à accoupler des dispositifs d'acquisition d'image (i, j) se trouvant à des distances données l'un de l'autre d'une manière fixe et en faisant un angle fixe entre eux, de façon telle que leur champ de vision commun, c'est-à-dire l'espace objet, soit déterminé et que cet espace puisse être observé d'une manière continue.

3. Procédé suivant la revendication 1, caractérisé en ce qu'il comprend l'étape consistant à choisir les points d'étalonnage de façon qu'ils couvrent l'espace à trois dimensions enregistré par les dispositifs d'acquisition d'image (i, j).

4. Procédé suivant la revendication 1, caractérisé en ce qu'il comprend l'étape consistant à prévoir un nombre de points d'étalonnage supérieur à 5 c'est-à-dire supérieur au plus petit nombre nécessaire dans le calcul des paramètres d'orientation.

5. Procédé suivant la revendication 1, caractérisé en ce qu'il comprend l'étape consistant à signaliser les points objets à mesurer à l'aide de marques d'aide à la mesure

6. Procédé suivant la revendication 5, caractérisé en ce qu'il comprend l'étape consistant a signaliser les points objets à mesurer à l'aide de spots lumineux agencés de façon à balayer l'espace objet.

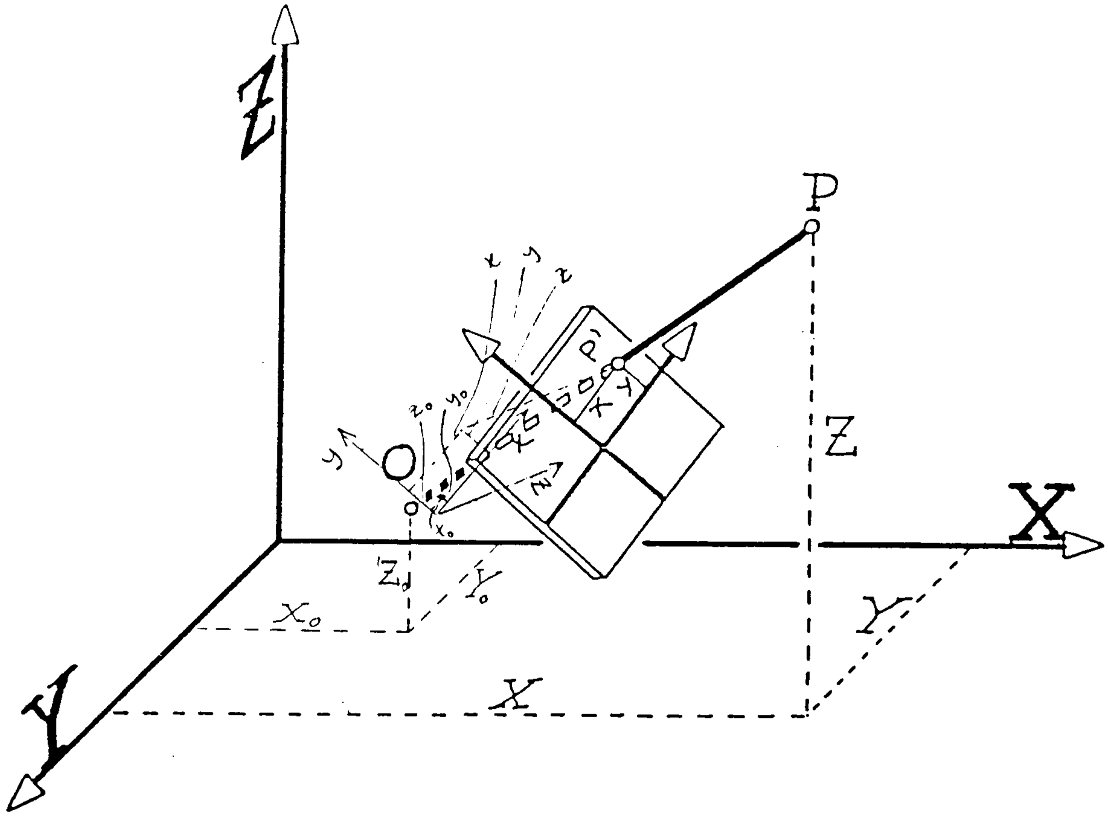

FIG. 1

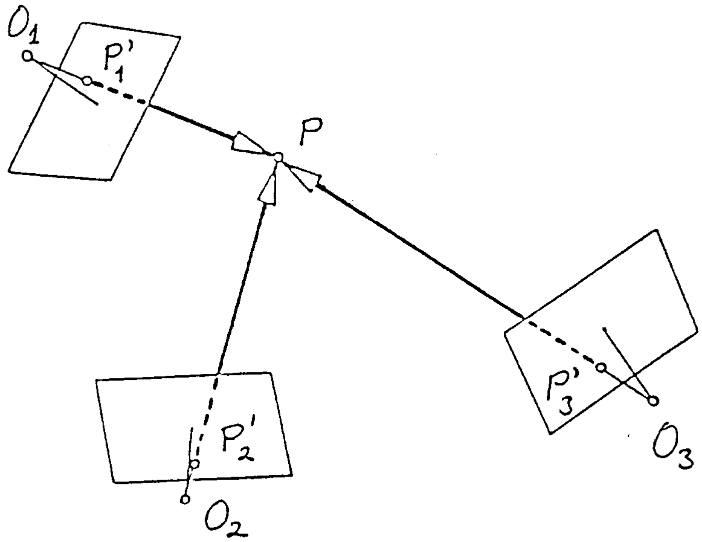

FIG. 2

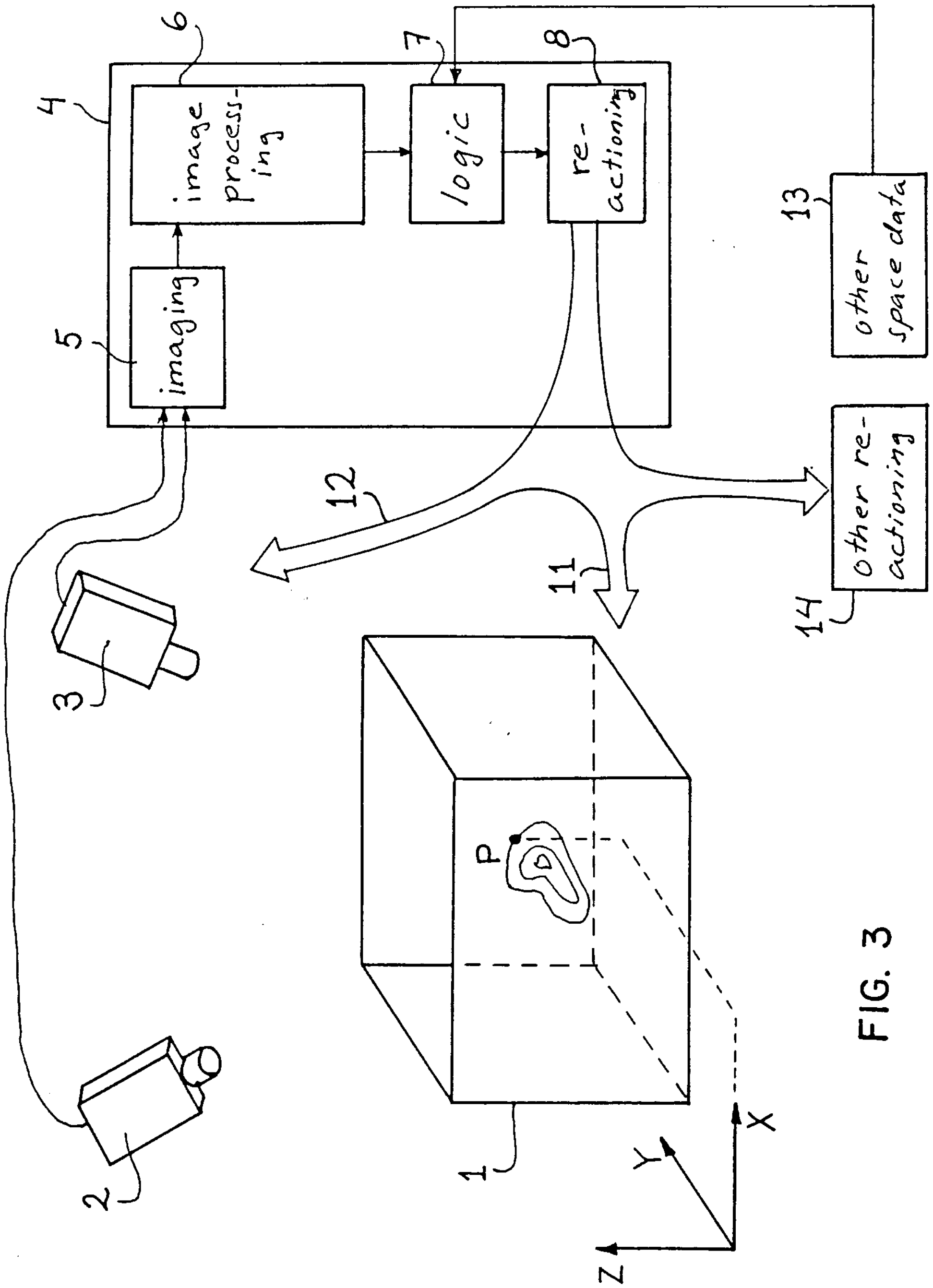
4
5
imaging
6
image processing
7
logic
8
re-actioning
13
other space data
14
other re-actioning
12
11
3
2
1
P
D
X
Y
Z

FIG. 3

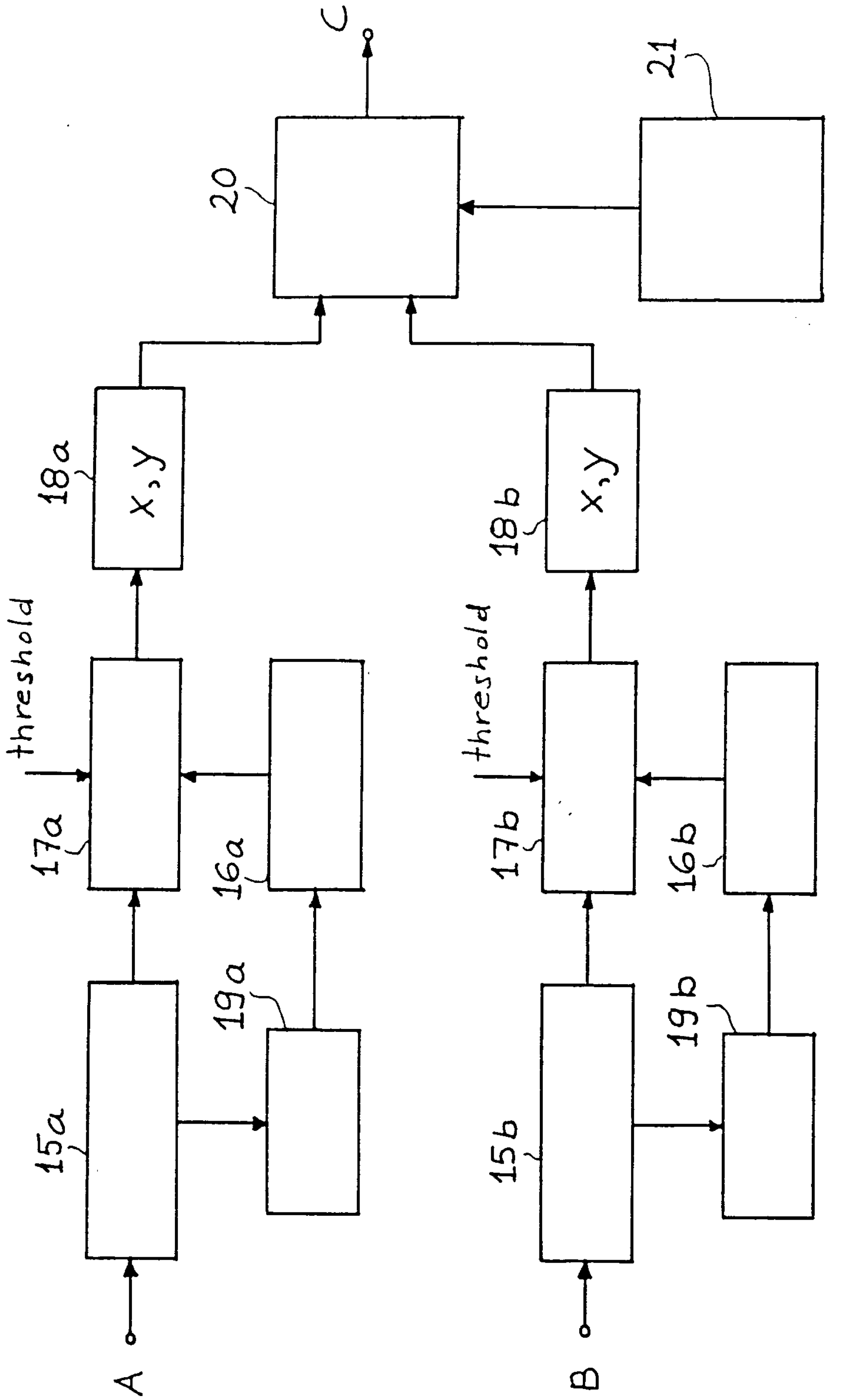
A
B
C
15a
15b
16a
16b
17a
17b
18a
18b
19a
19b
20
21
threshold
threshold
x, y
x, y

FIG. 4

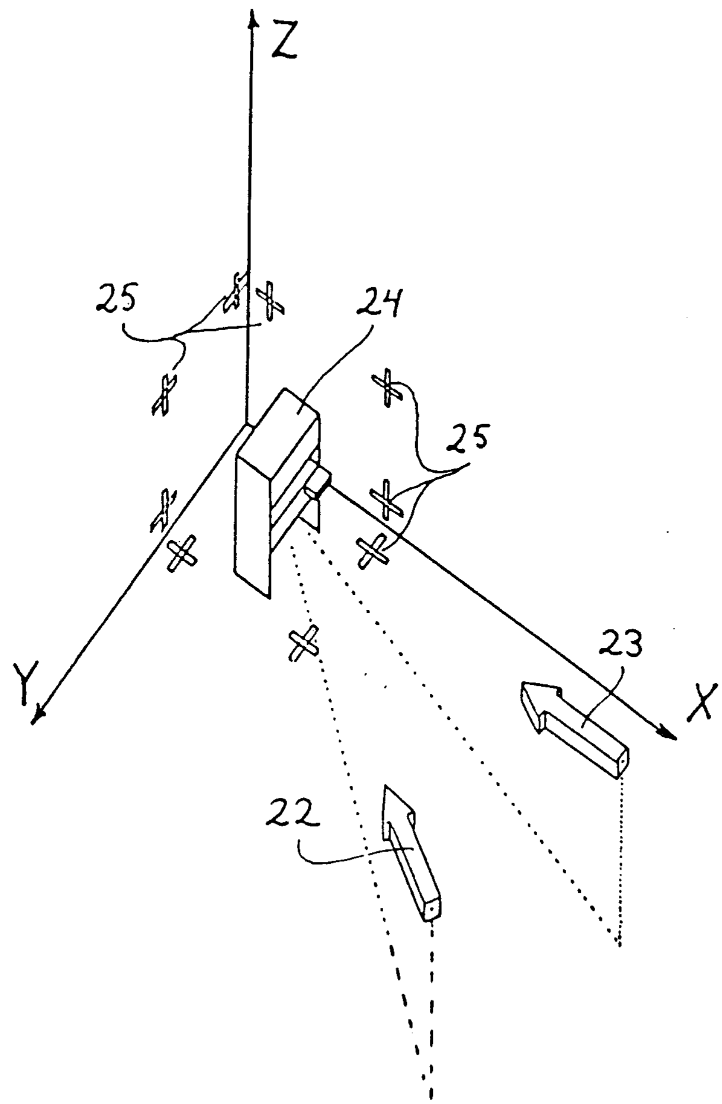

FIG. 5