DETERMINATION OF THREE-DIMENSIONAL COORDINATES OF THE OBJECT POINTS BY MEANS OF X-RAY AIMED PICTURES

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ABSTRACT

In the Moscow Tuberculosis Research Institute an original method of solving the X-ray photogrammetric task by means of aimed photographs has been worked out. The orientation elements of X-ray aimed photographs are determined by means of an additional stereopair of X-ray photographs of the normal case of survey.

The report gives an account of the theory, techniques and methods of the survey, as well as the results of the measurement error estimation.

In the medical and industrial roentgenology a method of aimed roentgenography is used when a cassette with photosensitive material is introduced into a hollow and placed in immediate proximity to the zone under investigation. This method allows to increase the resolution possibility of the picture and to exclude overshading of the zone under investigation with the structures situated on the opposite part of the survey object. The aimed picture facilitates decoding of the object structure and secures display of smaller pathological changes.

At the same time it is rather complicated to determine the location of the structures under investigation by means of a stereopair of aimed X-ray pictures. It can be explained by the fact that the interior and exterior orientation elements of aimed pictures are as a rule unknown. The method of the reverse photogrammetric intersection is not enough effective in this case, since the measures and the form of the object under investigation don't always allow to arrange the reference points properly. When the object is a considerably thick, the reference points fixed on its outer surface turn out blurred and difficult to be indentified on the picture.

In the Moscow Tuberculosis Research Institute a new method of solving the main photogrammetric task by means of aimed pictures has been worked out. This method provides using an additional stereopair of X-ray pictures with known orientation elements /I/.

Let us consider the techniques of the accomplishment of this method. For this purpose a standard one-tube X-ray apparatus or a special two-tube stereoroentgenographic device can be used /3/. The latter apparatus is more preferable, since it has a mechanism for alignment of the position of the X-ray tubes. The alignment helps to obtain the main point of the picture coincided with the beginning of the coordinate system $x_o = y_o = o$ and to have the principal distance of the left and right pictures identical $f_I = f_2$.

The patient I, examined for example, in connection with a pathological process in the upper wall of the mouth cavity, is placed on the deck 2 of the X-ray table (Fig.I). Under the deck of the X-ray table

a cassette 3 with an X-ray film 4 is placed. With the help of the holder 5 made of plexiglas, an additional cassette 7 with an X-ray film 8 is put into the mouth cavity 6 of the patient. The additional cassette is intended for aimed survey of the upper wall of the mouth cavity where the pathological object 9 was found. On the face wall of the aimed cassette four X-ray contrast marks I0 are fixed. The marks can be lead balls of I mm diameter. The survey object is positioned so that the area under investigation is within the zone of stereoroentgenographic overlap.

The X-ray survey is carried out by means of successive by-turn work of the X-ray tubes. First the left X-ray tube II is switched on, its focus spot is at the point F_I. After reloading of the film the cassettes 3 and 7 are put in the initial position. The repeated X-ray survey is carried out by means of the right X-ray tube, whose focus spot is at the point F_2.

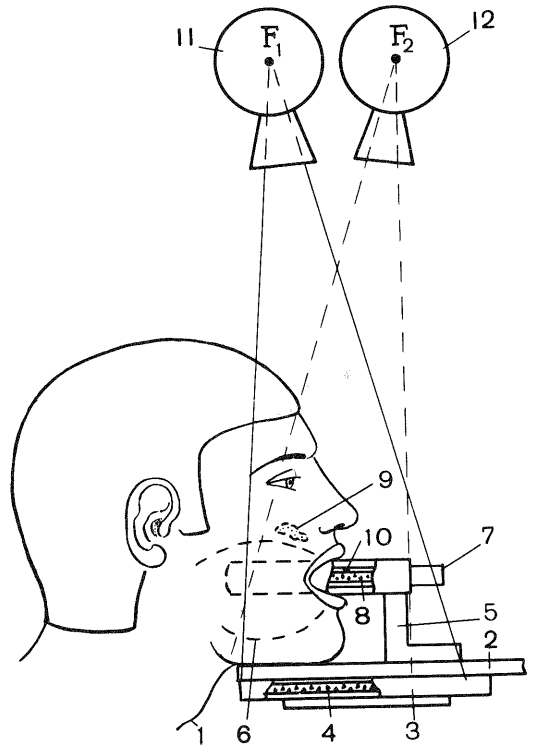

Fig.I.

The obtained pictures P_I, P_2 and P'_I, P'_2 form general and aimed stereopairs accordingly.

The aimed stereopair is used for interpretation of the revealed pathology and for measuring space coordinates of the object points of interest, and the interior and exterior orientation elements of the aimed stereopair pictures are determined according to the measured coordinates of the images of the reference marks on the general and aimed pictures.

The elements of the interior and the exterior orientation of the general stereopair pictures are known.

For determination of the interior and exterior orientation elements of the aimed pictures we use the known formulas of the relation between

the coordinates x_i, y_i of the picture point and the coordinates X_i, Y_i, Z_i of the corresponding point of the object:

$$x_i - x_o = -f\frac{a_1(X_i-X_o)+b_1(Y_i-Y_o)+c_1(Z_i-Z_o)}{a_3(X_i-X_o)+b_3(Y_i-Y_o)+c_3(Z_i-Z_o)};$$

$$y_i - y_o = -f\frac{a_2(X_i-X_o)+b_2(Y_i-Y_o)+c_2(Z_i-Z_o)}{a_3(X_i-X_o)+b_3(Y_i-Y_o)+c_3(Z_i-Z_o)}, \qquad (I)$$

where: x_o, y_o are coordinates of the principal point of the picture; f is the principal distance of the picture; X_o, Y_o, Z_o are coordinates of the photographing point; a_i, b_i, c_i are guide cosines which depend on the angle elements of the exterior orientation α, ω, $\varkappa$ /2/.

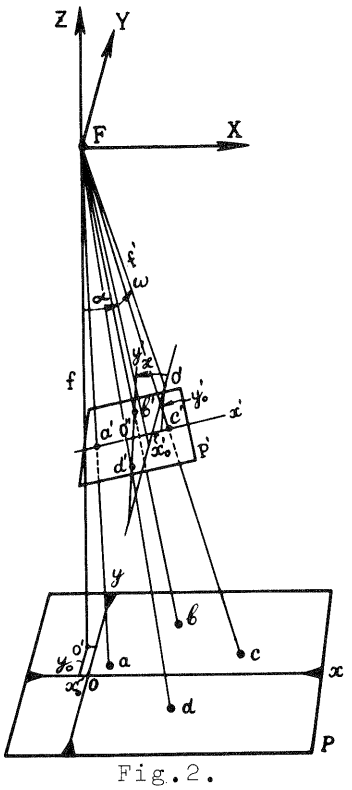

Fig.2.

In our case (Fig.2) the formulas (I) will be as follows:

$$x_i' - x_o' = -f'\frac{a_1(x_i-x_o)+b_1(y_i-y_o)-fc_1}{a_3(x_i-x_o)+b_3(y_i-y_o)-fc_3};$$

$$y_i' - y_o' = -f'\frac{a_2(x_i-x_o)+b_2(y_i-y_o)-fc_2}{a_3(x_i-x_o)+b_3(y_i-y_o)-fc_3}, \qquad (2)$$

where: x_i', y_i' are coordinates of the images of the reference marks a', b'... measured on the aimed picture in the system $x'y'o''$; x_o', y_o' are coordinates of the principal point of the aimed picture in the system $x'y'o''$; f' is the principal distance of the aimed picture P'; x_i, y_i are coordinates of the images of the reference marks a', b'... measured on the general picture in the system xyo'; x_o, y_o are coordinates of the principal point of the general picture in the system xyo' ; f is principal distance of the general picture P.

For determination of the elements $\alpha, \omega, \varkappa, x_o', y_o'$ and f' it is enough to solve the equation system (2), formed according to the three reference marks. When increasing the number of the reference marks and therefore the number of equations, the task can be solved with the method of the least squares.

The elements of the interior and exterior orientation are determined irrespective of the left P_1' and the right P_2' pictures of the aimed stereopair.

The technique of roentgenography allows to obtain the left and the right pictures of the aimed stereopair with the identical position of the cassette relative to the survey object. It facilitates considerably solving the X-ray photogrammetric task, since at this case the elements of mutual orientation of the aimed pictures $\Delta\alpha = \Delta\omega = \Delta\varkappa = 0$ and the conditions of stereoroentgenography correspond to the parallel case of survey with different principal distances of the cameras. At this case the coordinates of the object points can be determined as to the coordinates of their images on the aimed stereopair with regard to the orientation elements of these pictures by the known formulas of the coordinates intercommunication /3/:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = B \frac{f_2' \cos\nu \cos\tau + (x_2' - x_{o2}') \sin\nu}{(x_1' - x_{o1}') f_2' - (x_2' - x_{o2}') f_1'} \begin{bmatrix} x_1' - x_{o1}' \\ y_1' - y_{o1}' \\ -f_1' \end{bmatrix}, \qquad (3)$$

where: ν - the angle of the basis incline $\left(\nu = \arcsin \frac{f_2' - f_1'}{B}\right)$;

τ - the angle of the basis turn $\left(\tau = \arccos \frac{x_{o2}' \; x_{o1}'}{B \cos\nu}\right)$.

For error estimation of this method of roentgenotopographic survey a standard with ten control points in the form of steel balls of I mm diameter is used. The balls are fixed at the butt ends of the posts of different heights and placed on the flat and parallel base of a square form. The poles and the base of the standard are made of plexiglas.

The coordinates of the control points are determined in the rectangular system of the coordinates of the standard $OXYZ$ relative to the point No.I by direct mechanical measurements (the accuracy of the measurement is 0,05 mm).

For simultaneous obtaining of the general and aimed X-ray pictures of the standard we use a special device with two flat and parallel plates I and 2, made of plexiglas and fixed in mutual parallels on four support posts 3 (Fig.3.). Under the lower plate the holder of

the cassette 4 intended for obtaining a general picture lies. The cassette dimensions are 24 x 30 cm. The lower and upper plates have X-ray contrast marks for calibration of the general picture.

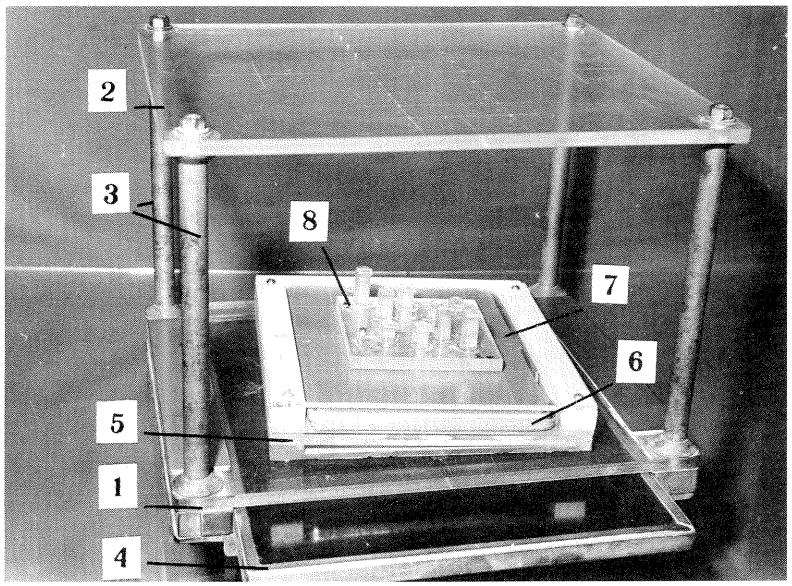

Fig.3.

On the lower plate the support 5 of the holder of the aimed cassette 6 is fixed. The support ensures an incline of the aimed cassette to the plane of the lower cassette. The holder of the cassette and the support are made of plexiglas. The dimensions of the aimed cassette are I3 x I8 cm.

The aimed cassette is adjusent to the plate 7, made of plexiglas, on which the standard 8 is fixed. The lower plane of the plate 7 is marked with nine X-ray contrast marks (steel balls of I mm diameter), playing the role of reference points. The reference points $1', 3', 5', 7'$ are fixed at the vertex of the angels square, the reference points $2', 4', 6', 8'$ are in the middle of each side of the square, and the point O' is in its center.

The standard is oriented on the plate 7 so that its axis X is parallel to the straight line, drawn through the reference points $4'$-$8'$, and the axis Y is parallel to the straight line, drawn through the points $2'$-$6'$.

The roentgenography device was placed on the deck of the horizontal table of the X-ray apparatus TUR I000 (GDR). The aimed and general cassettes, loaded with X-ray film, were put into the corresponding holders, and the standard was X-rayed simultaneously on two cassettes. After the reloading of the cassettes and the new positining of the X-ray tube the standard was X-rayed again.

The measurements of the aimed and general pictures are carried out by means of stereocomparator STR-3 of the firm "OPTON" (GFR).

Determination of the orientation elements of the aimed pictures was carried out with regard to the reference points $1', 3', 5', 7'$ by the formulas of relation of the coordinates (2) and by means of solving the correction equation by the method of successive approximations.

The coordinates of the control points of the standard were determined by formula (3) using the founded values of the orientation elements of the aimed pictures and the coordinates of the control points of the standard, measured on the aimed pictures.

By the results of stereoroentgenogrammetric and direct measurements a graph of errors of the coordinates of the control points /Fig.4/ was built, where for each point the radius-vector shows the value and the direction of the resulting error along the axes X and Y, and the figures (mm) mark the errors along the axis Z.

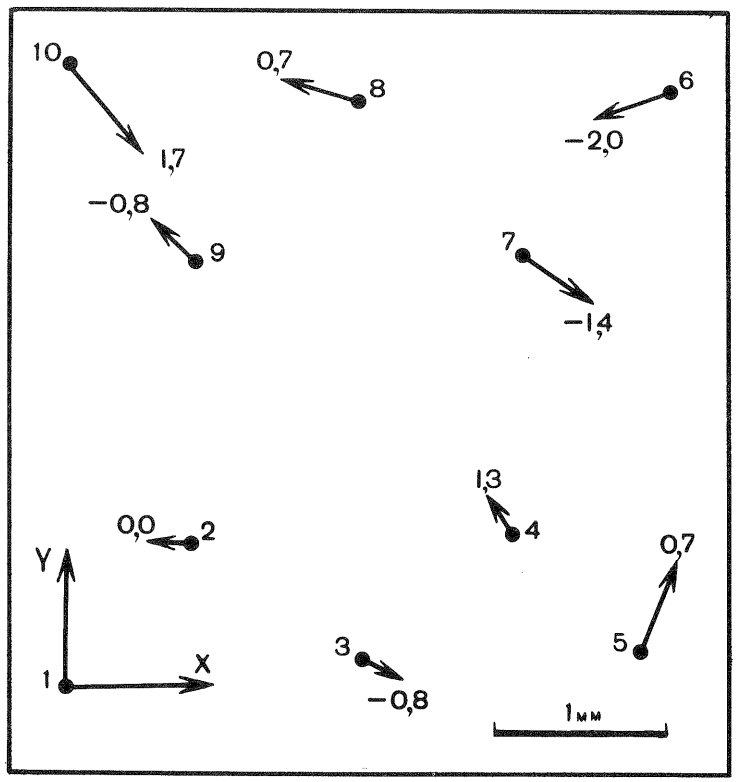

Fig.4.

By the results of the measurement of the ten control points (by the Gauss formula) the mean square errors of the determination of the difference of the space coordinates were calculated by the stereoroentgenogrammetric method: $m_{\Delta x}$ = 0,30 mm, $m_{\Delta y}$ = 0,28 mm, $m_{\Delta z}$ = I,I8 mm.

Thus, the suggested method provides for solving the photogrammetric task with a sufficient high accuracy by means of a stereopair of aimed pictures. The accurate photogrammetric data increases the quality information possibility and objectivity of the X-ray diagnostics.

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