RECOGNITION OF POLYHEDRONS WITH A RANGE FINDER

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Abstract

A recognition procedure with a range finder presented in this paper is developed for the eye of the intelligent robot studied in the Electrotechnical Laboratory. The range finder employs a vertical slit projecter which projects a. light beam on the objects. While the beam is moved in a field of view, the picture at each instant is picked up by a TV camera. The distance to each point can be obtained by means of trigonometrical calculation. The recognition procedure using thus obtained information is free from the effects of the arrangement and shadow of objects.

1. Introduction

The recognition of 3-dimensional objects and the measurement of their parameters are necessary for intelligent robots that manipulate objects on the basis of visual information. The recognition procedure* of polyhedrons based on the line drawing of a scene has been heretofore developed.(1),(2),(3) However, extraction of a line drawing is difficult, and if even one edge of an object is incorrectly detected, the object may be recognized as a quite different one.(4) Besides, the constraint of the position, the arrangement and the shape of the objects are necessary for the measurement of their 3-dimensional positions and sizes.

In order to measure the 3-dimensional position directly, a range finder has been studied, and two typical methods have been developed up to now. One is to project a spot light and detect its reflecting light,(5) and the other is based on the stereoscopic view. The former takes a long time to got the range of many points of objects because it requires the rotation of a spot beam for the measurement of each point. The latter requires a great deal of calculation to determine the corresponding points of the two pictures.

The method presented here employs a vertical slit projector and a TV camera to pick up its reflected light. By rotating a projector from the left to the right, the distance of many points in a field of view is obtained quickly.

2. Construction of a range finder

The range finder employed in this study projects a light beam through a vertical slit in a projector at a constant distance from a TV camera as shown in Fig.l.

While the projector is rotated, pictures are sampled by a TV camera at predetermined instances and the information related to each picture and a corresponding slit beam angle is stored. If each position of a slit in the picture is determined from a stored picture, then its 3-dimensional position can be calculated by means of trigonometry. The input of picture data is controlled by a computer as shown in Fig.2, and the video signal of each picturee is converted into a digital signal by a preprocessor.(7) This preprocessor divides the frame of a camera into 256 x 256 picture elements, and 64 x 64 elements are sampled in one scanning time.

3. Recocrmtion of polyhedrons

The recognition procedure of polyhedrons based on a set of picture data and slit beam angles involves (l) determination of slit positions, (2) composition of lines, (3) composition of planes , (4) determination of the position of planes, and (5) composition of polyhedrons. In (l) - (3), only picture data are used; in (4), the 3-dimensional position of the plane is obtained with slit beam angles. In (5), the objects are recognized based on the interrelation of planes. There is an alternative process of estimating the distance to the surface for each point and then analyzing the two dimensional field of distance to find surface. This method takes a long time for calculation of the distance for evely point. The process presented here calculates only the end points of lines to determine the psoition of planes. Each procedure is described in detail in the foilowing.

(1) Determination of slit positions

Each picture corresponding to a slit beam angle is stored in binary form where each picture element is 1 if the light intensity is above the threshold, and 0 otherwise. At first this picture is smoothed to eliminate the effect of noise caused by a vidicon camera or a preprocessor. Let the binary picture element be denoted by the mutrix element C(i,j), the output of smoothing operation C'(i,j) is the majority of C(i,j), C(i, j-l) and C(i,j+l). By examining elements C'(i,j) along the jth row, from among the sequences whose element successively takes value 1, the longest sequence is selected, and its position is established as the center of the sequence. This operation is carried out for every j, and then a slit position is denoted by the sequence of points I(j). Fig.4 illustrates the sequence of points for each slit position of a picture.

(2) Composition of lines

If polyhedrons are placed in the background that consists of planes, a projected slit image is generally composed of lines as shown in Fig.5. In the image, a discontinuous terminal point of a line corresponds to a discontinuous boundary point of a plane and an intersection of two lines corresponds to a boundary point of two adjacent planes. In the first step for composition of lines from the sequence of slit points I(j), discontinuous points are found and each set of I(j) whose elements are regarded as continuous is listed. A set of slit points $\{T(j),\ J=J_s \sim J_e\}$ constitutes a line or several adjacent lines. The next step is, therefore, to find the number of lines included in a set of slit points, and the terminal points and the equation of each line. At first a sequence of I(j) which constitutes a line segment is found. This sequence $\{I(j_i),\ J_i=J_{-3}, J_{-2}, j_{-1} J_o, J_{-1}, J_2, J_3\}$ must satisfy the following two equations:

$$|\Delta_1+\Delta_{-1}|+|\Delta_2+\Delta_{-2}|+|\Delta_3+\Delta_{-3}|\leq \theta_s \quad (1)$$

$$|(\Delta_1-\Delta_{-1})+(\Delta_2-\Delta_{-2})+(\Delta_3-\Delta_{-3})|\leq \theta_\ell \quad (2)$$

where $\Delta_1=I(j_1)-I(j_0)$, θ_s=constant and θ_ℓ=constant. Eq.(1) and Eq.(2) provide the measures of symmetry and linearity of a line segment, respectively.

Starting from this line segment, $\{I(j),\ J=j_s \sim j_e\}$ is tracked upward and downward until the terminal point of a line is found. This algorithm is, as shown in Fig.6, to track the slit point, sequentially correcting the equation of a line. Fig.7 shows the result of the tracking and Fig.8 shows the lines thus obtained.

(3) Composition of planes

This operation groups linos obtained in (2) into classes whose element constitutes a plane. If slit images are sampled at constant time intervals, then the images of the slits projected on the same plane form nearly parallel lines at constant intervals. Adjacent lines which correspond to slit beam angles $\alpha_1, \alpha_{1+1},$ ——— are grouped into the same class, and then the lines in a class are again divided into different classes based on their intervals. After this operation, each class of lines constitutes a plane. The principle of the above two classification algorithms *is* about the same as that of tracking in (2); i.e., at first find the segment of a plane and then examine the next line if it belongs to the plane until the boundary line of the plane is found.

(4) Determination of the positions of planes

A class of lines obtained in (3) does not precisely compose a plane because of errors in various phases of the procedure. In this stage, the 3-dimensional position of each plane is calculated from the class of lines and their corresponding slit beam angles. Let a plane consist of n lines and the equation of the plane be denoted by bx + c = 0. Let L(x., b, c) denote the Euclidian distance between the plane and a point x. on the ith line, then $L(x_i, b, c)$ can be easily calculated.

Let the integral of L^2 (x., b, c) be defined as

$$S_i = \int_{\text{on the ith line}} L^2(x_i, b, c)\, dx_i \qquad (3)$$

The coefficients of the equation of the plane, b and c, are determined by the least squares method so that the following value J is minimized.

$$J = \sum_{i=1}^{n} S_i \qquad (4)$$

(5) Composition of polyhedrons

In this process, the objects are recognized and their parameters are measured from the shape and the position of the planes. Although this algorithm depends on the purpose of the particular recognition, an example of finding the shape, size and position of polyhedrons is described here. First, the background planes are eliminated from the list of the obtained planes. The vertical planes are picked up from the rest of the planes and their geometrical relation is examined. Next, the horizontal planes on the vertical ones are found. If a horizontal plane is found, the shape of the polyhedron is recognized according to the shape of the horizontal plane and the adjacent vertical planes. If it is not found, the shape of the polyhedron is estimated from the vertical planes only. Once the shape of the polyhedron is determined, its size and position is obtained easily because the shape and position of all the surface planes of the polyhedron are known. The result of the recognition is illustrated in Fig.9.

This recognition procedure has low sensitivity to noise because it utilizes 3-dimensional information. The slit image, for example, may be broadened according to the direction of planes. In this case, the center points of the slit image may not make straight lines as shown in Pig.10. However, based on the 3-dimensional position of the planes, the polyhedron is correctly recognized. The result of this procedure for Fig.10 is illustrated in Fig.11.

4. Conelus ions

A range finder is used to project a light beam through a vertical slit on the polyhedrons. Based on the 3-dimensional position of the slit image, the objects are recognized and their parameters are obtained. This method determines not only the boundary of the polyhedrons but also the 3-dimensional position of their surface planes. Thus, recognition is reliable compared with one based on the line drawing of the objects. In addition, this range finder may be used to measure the 3-dimensional position of any point for input to the usual recognition methods

The defect of this device is in the mechanical rotation of the slit projector, but the mechanical part may be reduced by using a mirror.

Acknowledgements

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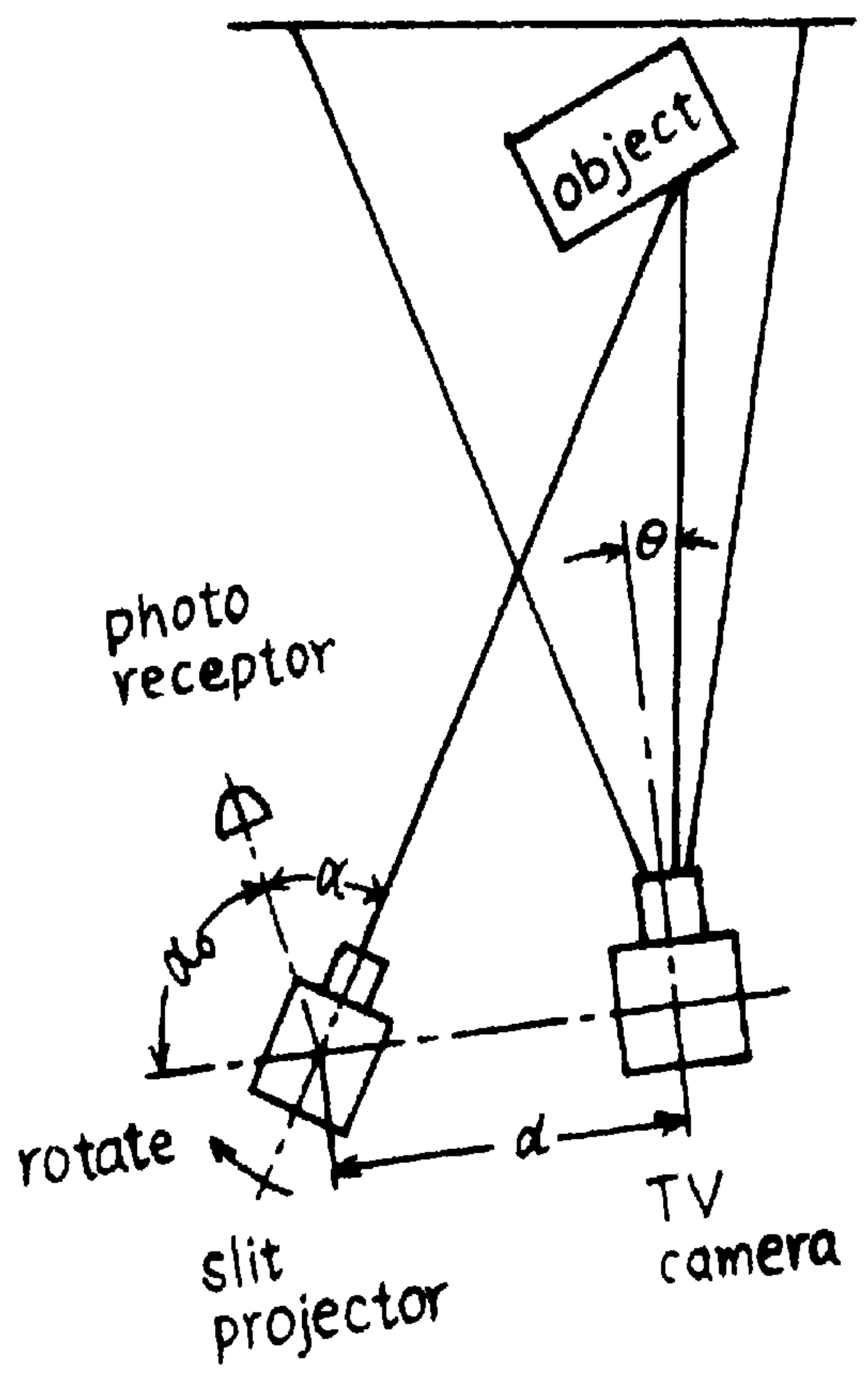


Fig.1. Fundamental schema of the range finder

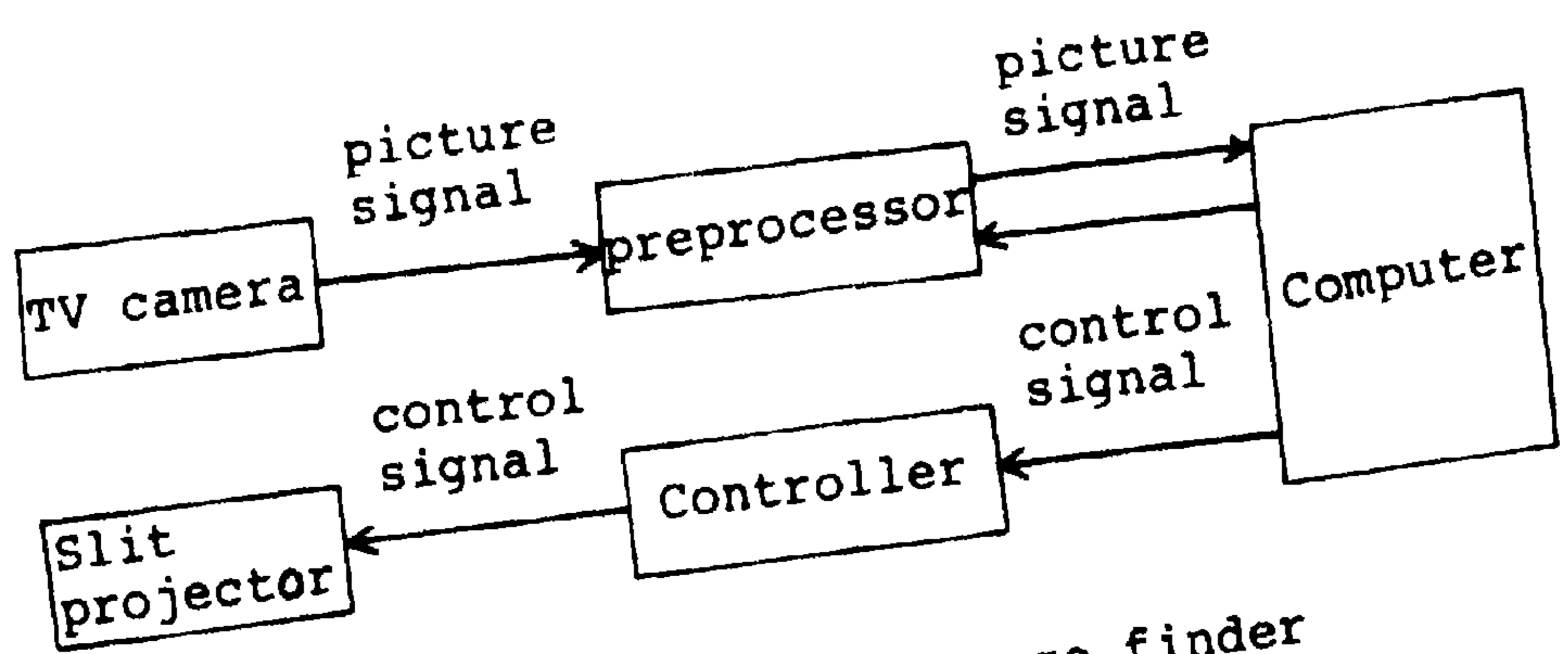


Fig.2. Construction of the range finder

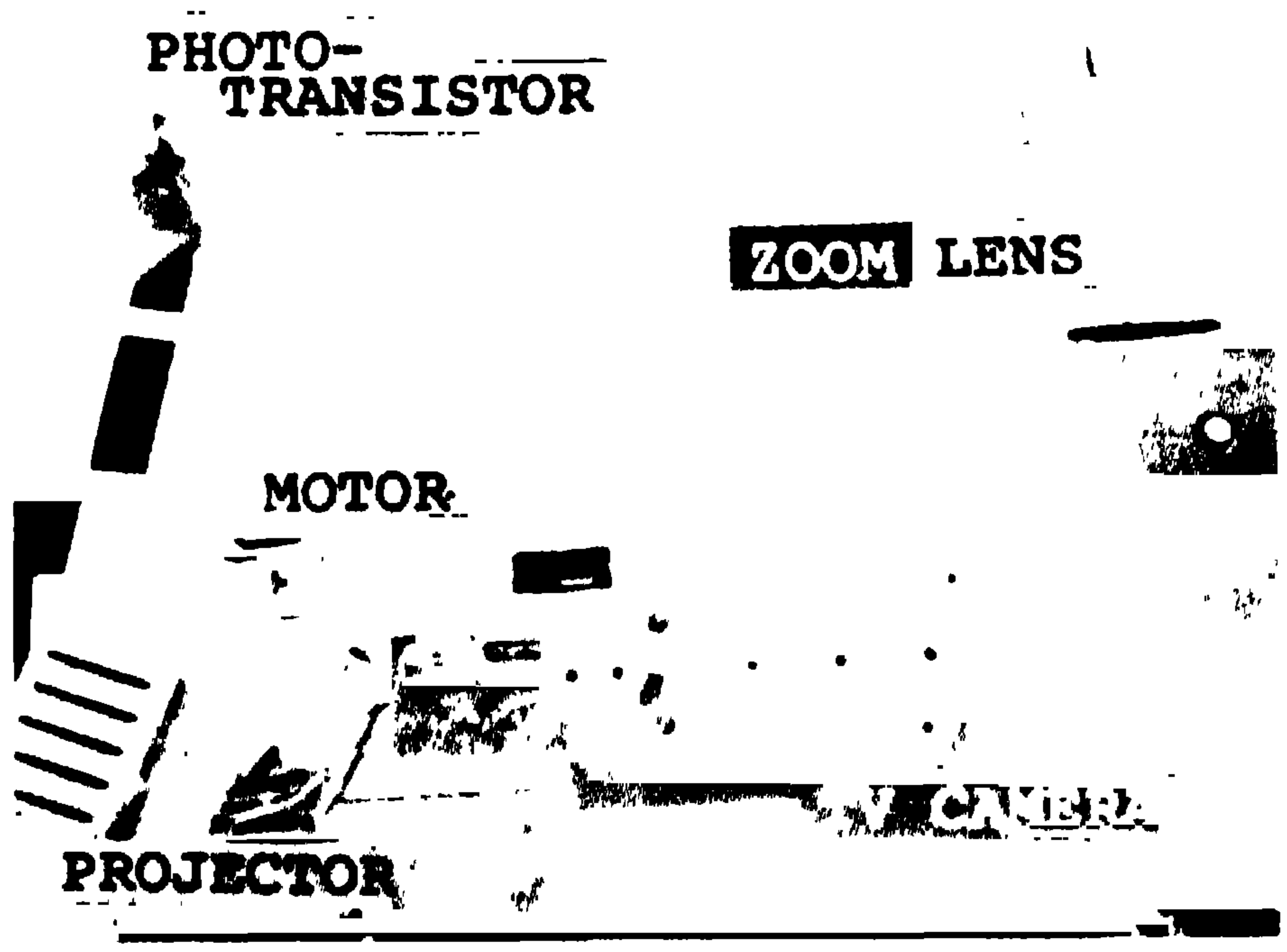


Fig.3. The range finder

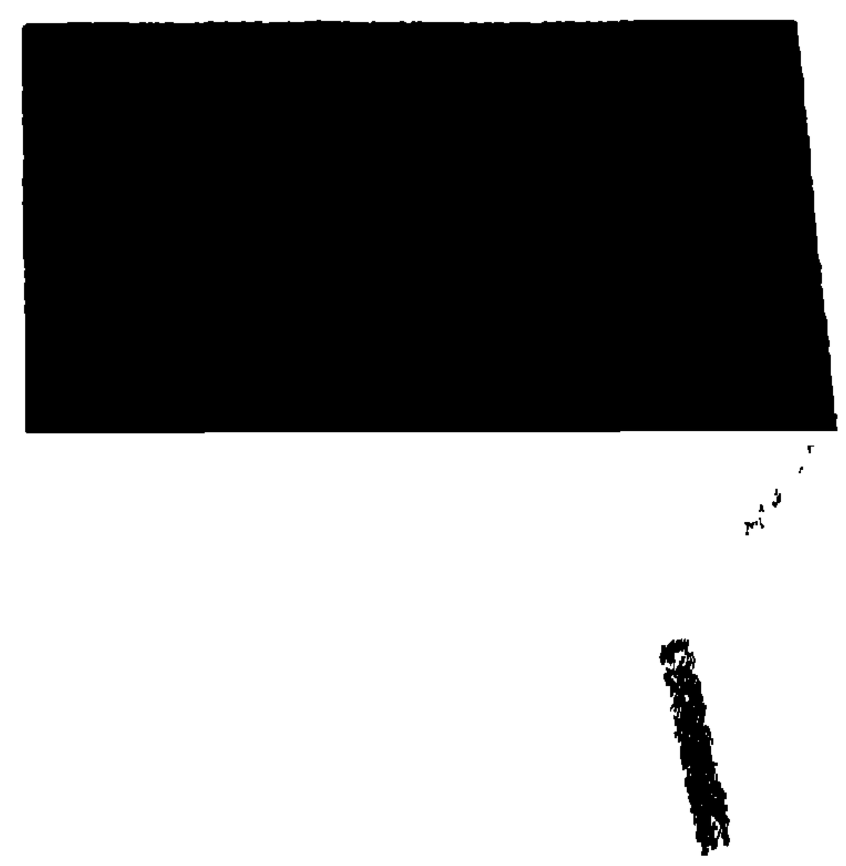


Fig.5. Projected slit beam

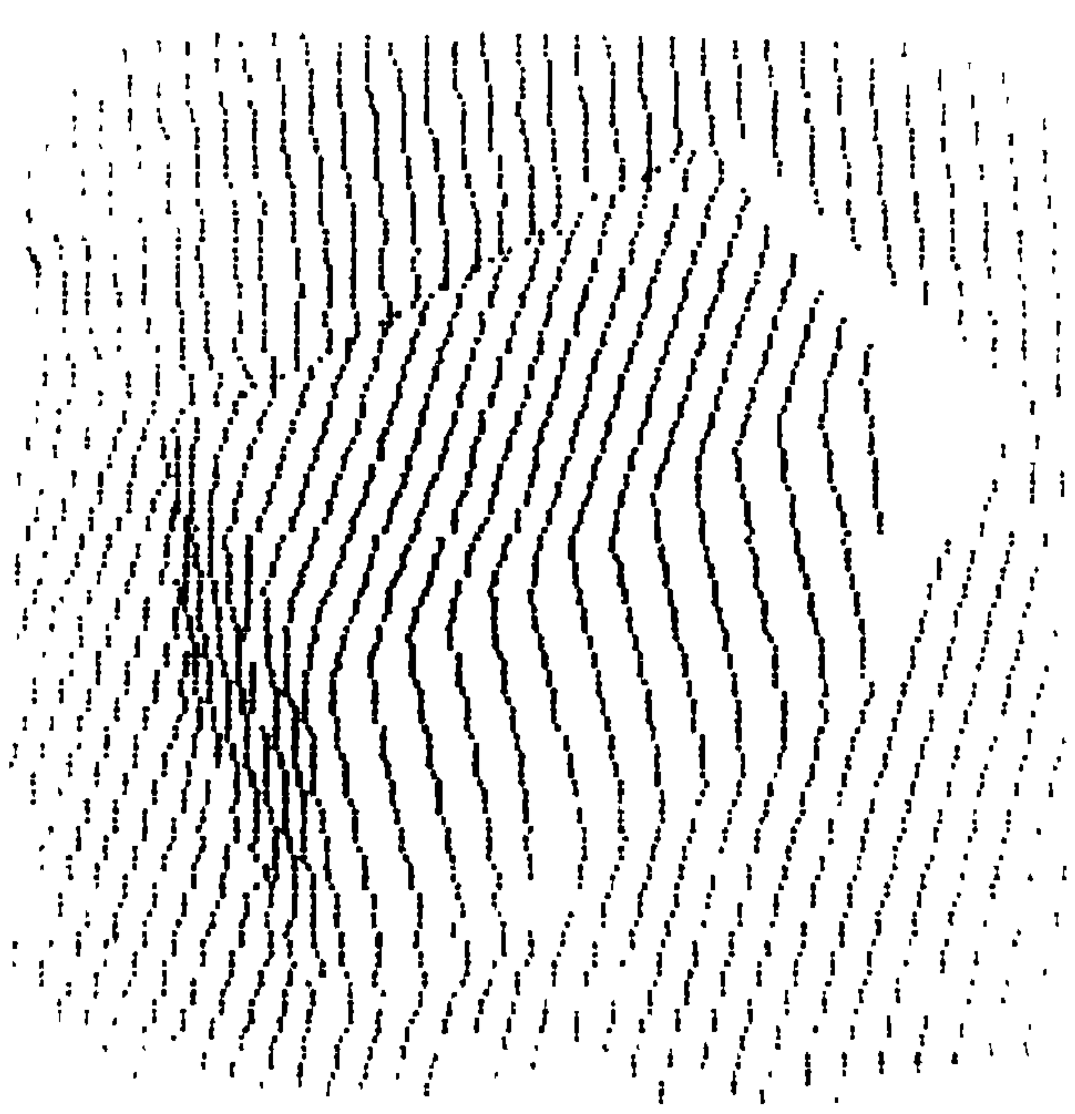


Fig.4. The center points of slits

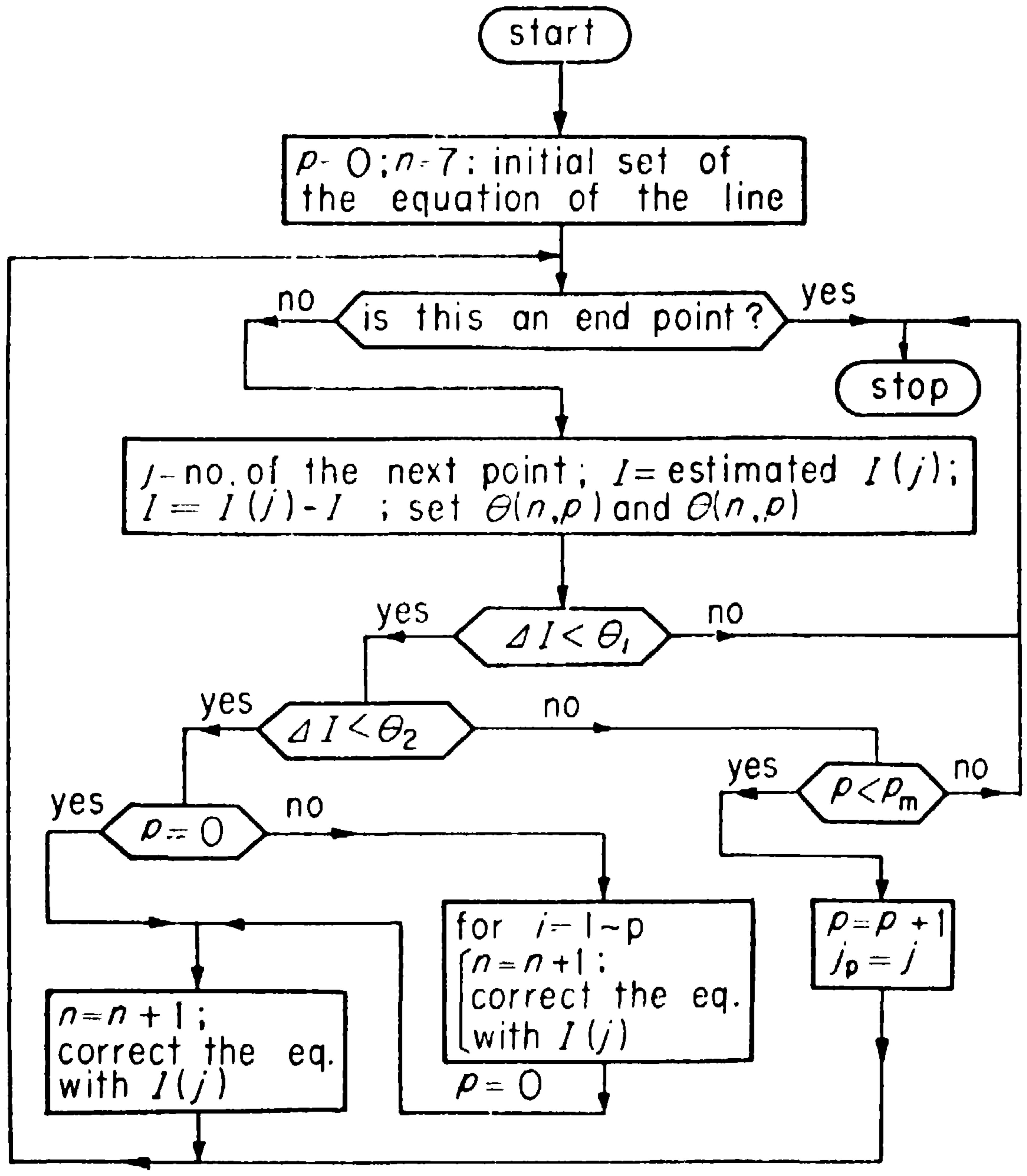
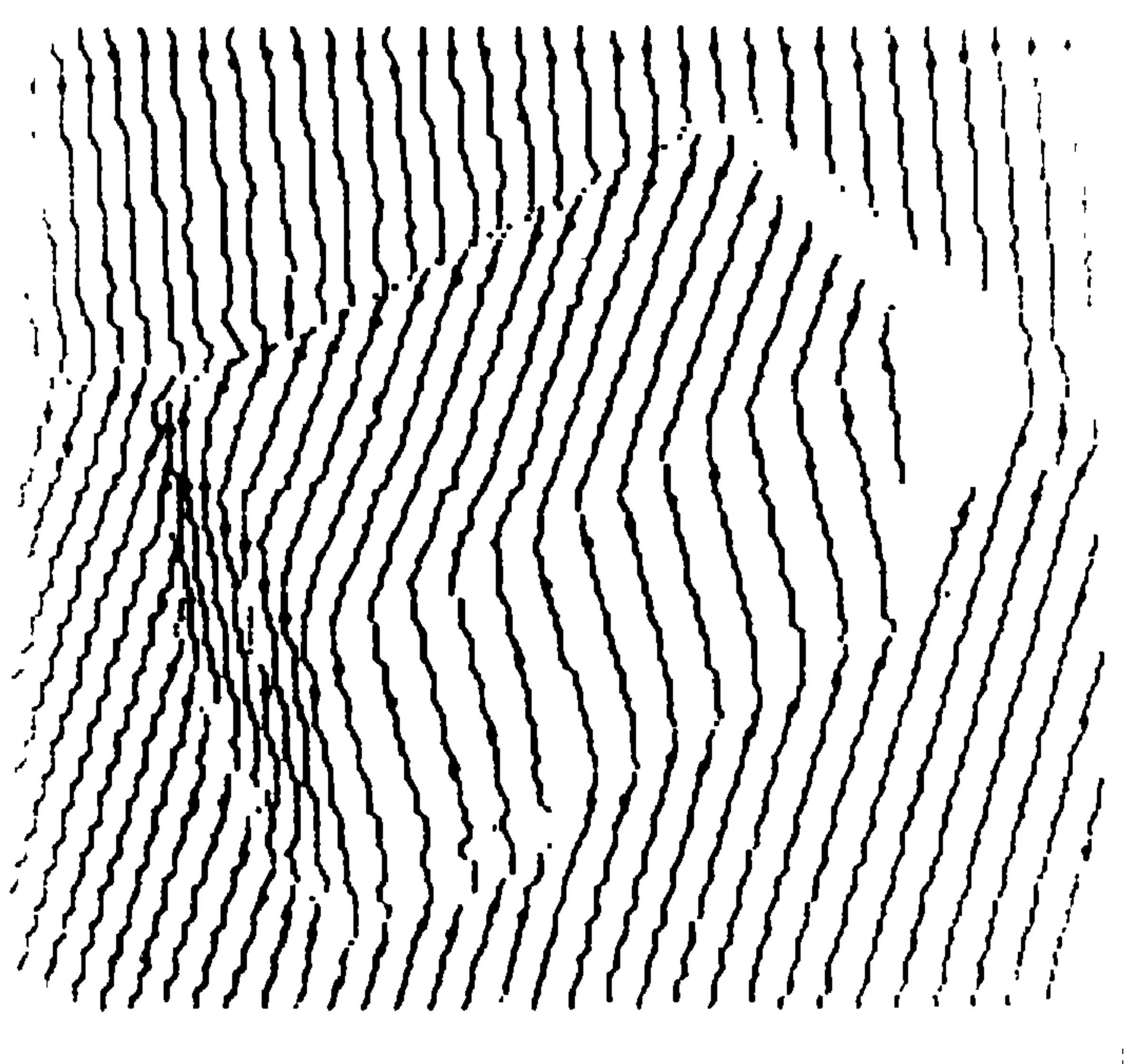


Fig.6. Flow chart of tracking



◆ :starting point

Fig.7. The result of tracking

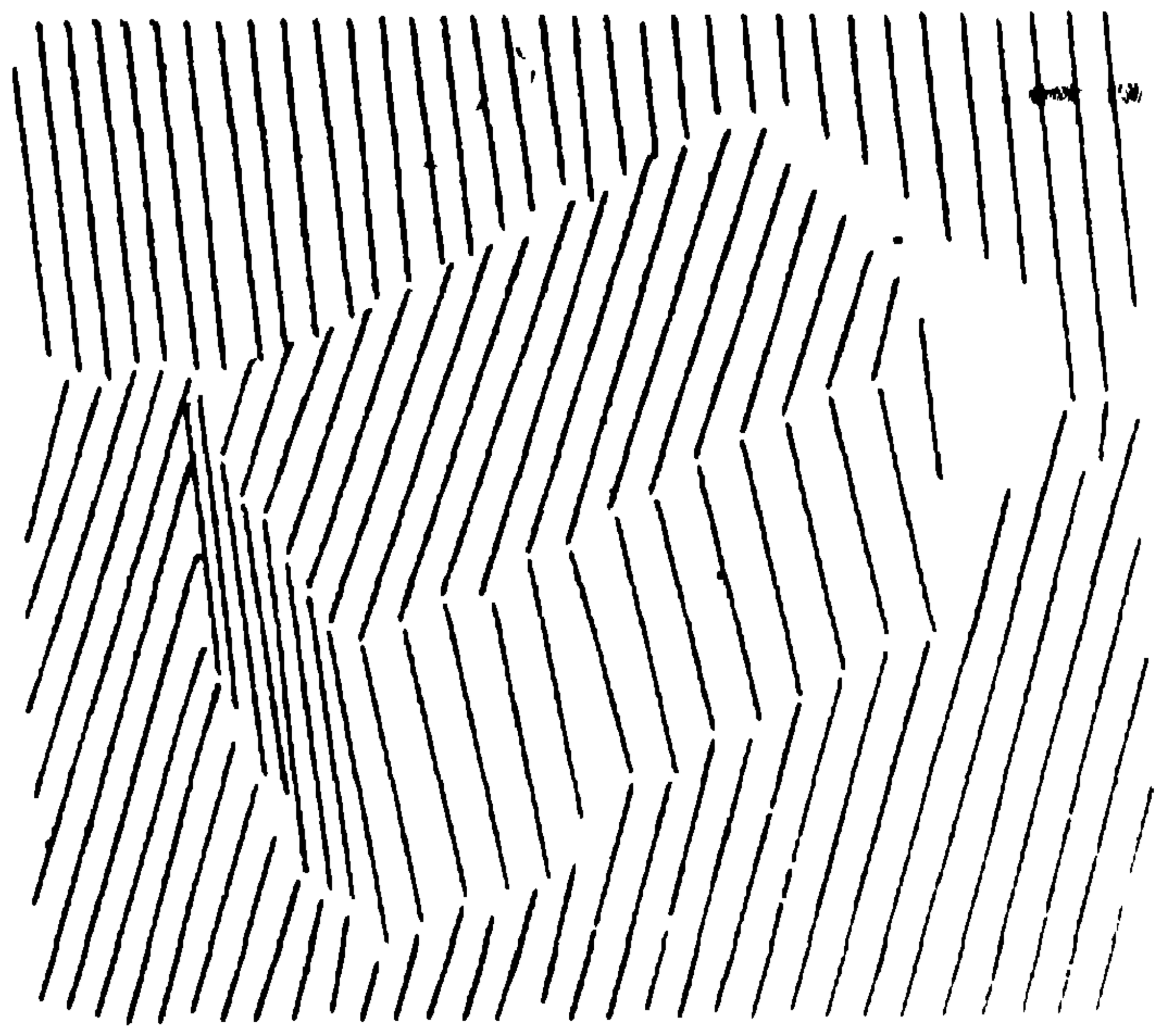


Fig.8. Obtained lines

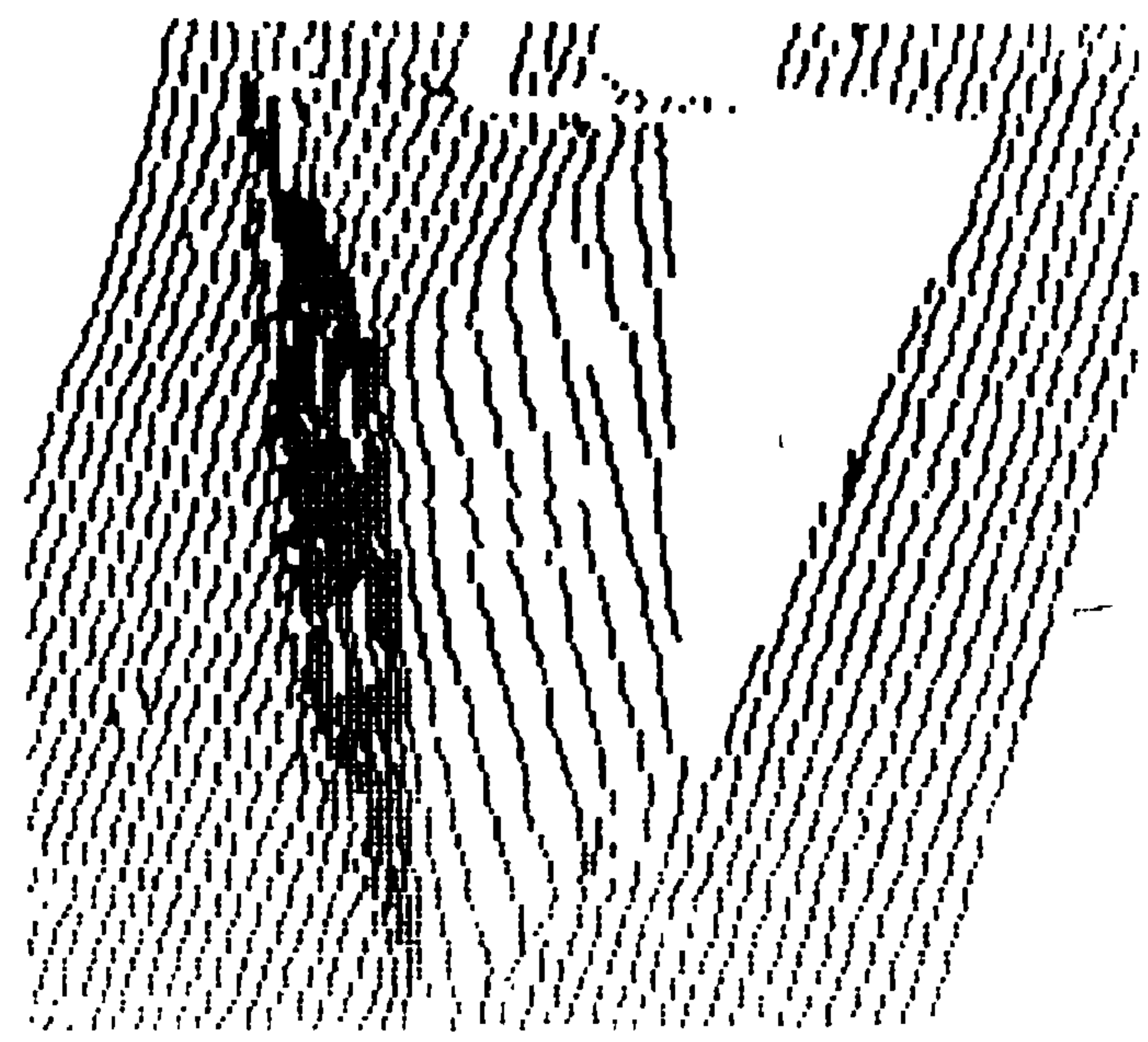


Fig.10. The center of the slits

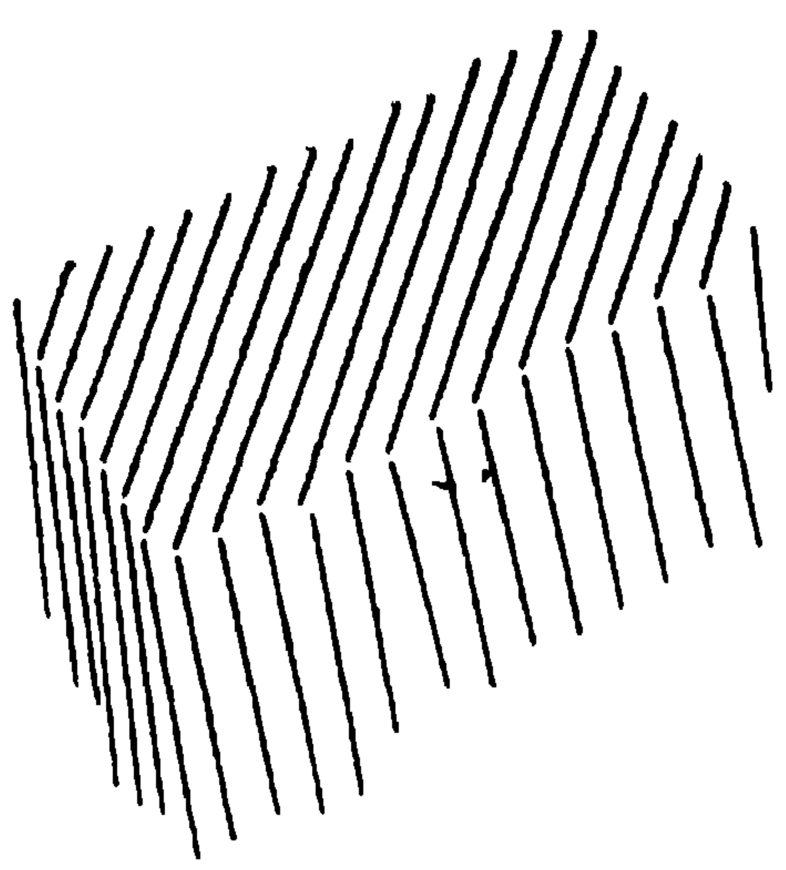


Fig.9. Recognition of rectangular prism

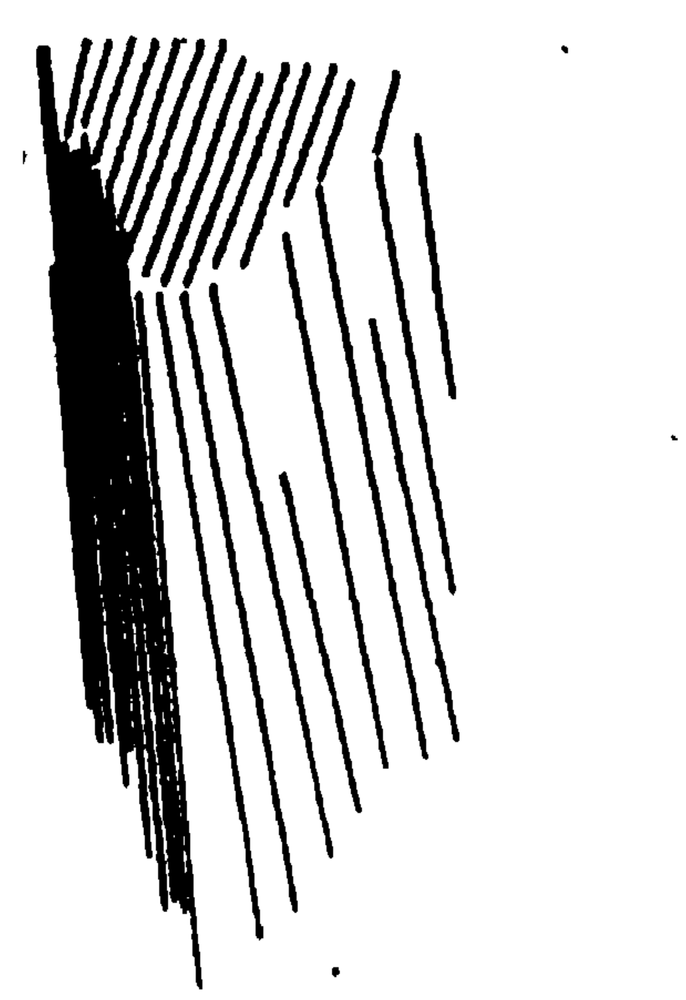


Fig.11. Recognition of triangular prism