VISUAL-TACTILE SYMBIOTIC SYSTEM FOR STEREOMETRIC PATTERN RECOGNITION

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Abstract

This paper describes a preliminary component for a symbotic system of visual and tactile senses. The concept of symbiotic system will play an important role in the realization of artificial intelligence. That is, visual and tactile sensors are the essential ones for both recognizing and handling any kind of object.

For correct manipulation of objects it is necessary to know their spacial characteristics, as, for example, shape and position.

Information on these characteristics of objects is picked up by human beings through visual and tactile senses. Before direct contact with the object, when the visual sense plays an exclusive role,decision (depending on the principal task) is based only on optical information. From the moment of touch, both optical and tactile information begin to be coordinated. At this moment the visual sense can be partly released for other tasks and the tactile sense may become dominant In picking up object information.

It is clear that visual control usually has the dominant, but not absolute, role in the recognition and manipulation of objects.

The system proposed here is a new kind of system wherein an obscure visual image can be identified as a clear Image by the coordination of visual and tactile senses.

This system is quite effective when the object is cubic and inseparable from its circumstances, as in the case of the recognition and handling of objects in industrial use, underwater application, and so on.

Introduction

Solving problem of stereometric pattern recognition is important for realizing practical artificial intelligence systems. It appears likely that dynamic visual-tactile information processing will be used in several such man-machine systems. In this paper we will describe mainly the tactile information processing techniques for designing a symbiotic system.

Some studies of tactile displays have been made; for example, a conference on tactile displays was held at Stanford Research Institute, Menlo Park, California, on April 3 and 4,1969. A major objective of this conference was to examine current neurophysiological and psychological theories to determine the extent that a rational basis for the design of dynamic tactile displays could be developed, (1)

In general, the tactile model includes a pressure-electric transformation element, and this system is modeled after its physiological counterpart.

It is well known that the sensory nerve and it. ending which controls the tactile sense exist in skin. The particular model eliminates the function of the temperature, pain and touch sensation of the tactile sense and arranges a piezo-electric element of strain sensor corresponding to pressure sense.

The tactile sensor to be described here consists of normal on-off elements. The feature of this tactile system is to provide the finger with tactile sensors to move along the surface of a object when one of the sensors touches it.

Stereometric pattern recognition is made use of in the system for manipulating objects. The particular device for manipulation is called a manipulator; it is an artificial hand with a tactile sense. We consider these systems to correspond to human sense organs and call them visual and tactile systems, respectively. The visual system is responsible for spatial information and the tactile system for detailed shape information of objects. The purpose of this symbiotic system is to provide a kind of artificial intelligence by using both visual and tactile information.

System design is an Important part of this kind of study. In order to provide a framework for this symbiotic system, a general approach to its system design has proposed by Aida and Kinoshita (2), the experimental structure is illustrated there.

System Design

An important feature of this symbiotic system Is that the information processing is carried out by coordinating visual and tactile information. The system described here can be actualized in two forms: one is an open-loop structure and the other a closed-loop one which includes learning techniques.

In the open-loop symbiotic system, the output of the visual sensor serves as an input to the tactile sensor, and this system can represent a time sequence of events from visual to tactile sensor. A simple block diagram is illustrated in Fig. 1 (a).

Although in Fig. 1 (b) the visual sensor and the tactile sensor are in chronological sequence, the results from the tactile sensor are fed back to influence what will later occur at the visual sensor, for example, a grey level or scanning method control. The resultant output of the combination appears as the image of ft visual display, and the effects of changes in the individual blocks on the resultant output are different for the open-loop and closed-loop configurations .

In the open-loop symbiotic system, visual processing is only used to decide the position of the object, whose image is obscure, then the tactile sense moves towards the object and touches its predetermined part to get a detection matrix for the object. After matrix processing, tactile information is converted into a visual signal to present a clear image of the visual desplay, but this process has only been for the edges of the object.

Therefore, pattern recognition by the open loop symbiotic systems is carried out step by step as follows:

1) Range finding and locating of the direction of gaze with respect to visual sensor. Visual image of the object is partly or completely obsucre.

2) Positioning of ohscure part by the divided area on the image screen.

3) Tactile sensor moves to the object and touches the obscure part of the object on the images screen.

4) Detection matrix is made on the basis of 3).

5) Convert tactile information to visual display signal.

6) Loop 3) to 5) until the obscure part on the image screen is cleared.

A block diagram for the open-loop and the closed-loop symbiotic system is shown in Fig.2, it shows conceptually a block diagram of the symbiotic system with visual and tactile senses. This system consists of four parts; a part which processes information from the visual sense, for example, a vidicon camera, a part which processes those from the tactile sense, a part which integrates the information, and a display device which indicates the process.

The initial scene of objects obtained by the vidicon camera and its displayed image is obscure. It has been impossible to recognize objects with this primary image- only. However this initial information establishes the existence and the position of the objects. Variations in brightness are extracted by using the procedure of lateral inhibition, and then the digitalized image is cut off by an appropriate threshold value. The process provides the beginnings of feature extraction and the recognition of objects, but for indestinct features. The finger with the tactile sensor is stretched out, and the features *of* the parts of objects are extracted by being touched with the finger.

The tactile system searches out and recognizes states of the object surface for obscure parts of the picture. The feature is taken by using a contact distribution which takes account both of tactile information and of the finger's movement. The feature on the image is transformed to a line drawing picture which is processed with the detection matrix, elements of which are abstracted by the contact distribution generated by the tactile sensor. The function $D_{mn}(u,v)$ of two iunctions p(u,v) and $A_{mn}(u.v)$ as shown in Fig.3 is defined as

$$D_{mn}(u,v) = \iint_D p(\alpha,\beta)A_{mn}(u+\alpha,v+\beta)\,d\alpha\, d\beta \quad \alpha,\beta \in D$$

It is considered that the output D_{mn} indicates the same features pattern in the window A_{mn} as the pattern of the detection matarix. If the output equals zero, the feature of object is not extracted in the window.

Then, the system adjusts its parameters, which are gradually varied with the observation of D_{mn} in the window established from the result of recognition. Three kinds of modified parameters are considered, they are processed according to the following order: 1) focus of vidicon camera, 2) contrast, 3) elements of detection martrix. First, it is necessary to adjust the locus so that the clearest feature of the pattern can be obtained. If the focus is off the point, the image becomes obscure. In the symbiotic system, the focus is adjusted by a visual sensor driving signal as shown in Fig.2, and the distance from the position of finger is calculated.

Second, the constrast is gradually adjusted. If the contrast is highly intensive, the feature of pattern is lost. The A_{mn} in the picture is established as the unknown part for the recognition of the picture and stored pattern. As the part of the object corresponding to A_{mn} is recognized by the tactile sense, parameters of visual system like contrast or brightness are adjusted BO that the recognition will coincide with that from tactile sense. Moreover, a shadow pattern of the object is varied with chages in the derection of the light thrown on it and the feature of the pattern is extracted more easily.

Third, the element of detection matrix is changed correspoding to the sensitivity value *of* D_{mn}. As described above, the image obtained from the visual scene is transformed automatically into a scene with clear edges. With this image, the whole scene is recognised.

Thus, in the closed-loop symbiotic system, whenever the 'object is touched by the tactile sensor, the tactile information controls parameters of visual aensor, such as the threshold level of the visual-processing system, and a clearer image results.

Artificial Tactile Perceptions

The assumption underlying tactile exploration is that if a device is able to feel a contact situation with the object and to identify automatically the surfaces which limit it, then it is possible to get a quantity of Information sufficient to enble a computer to characterize the object from a geometrical point of view.

Using sensors of a particular kind, it may be possible to characterize an object also from other points of view, thermal, chemical, and so on.

The computer can make some elementary decisions about the shape and the kind of the examined object and subsequently can give some simple orders to an actuator.

Computer Simulations of Stereometric Forms

A lot of methods have been proposed for visual processing (3). This section, therefore, describes some computer simulations of the tactile-processing system which is under development to realize this kind of system. It is difficult to say how large a part the tactile sense plays in the field of pattern recognitions. As the first step in this determination, we consider the exploration oi space patterns by direct contact only, that is, by the sense of touch. Then, we are trying to optimize the prehension of objects at a lower level in the hierarchy of manipulation control, dependent on their stereometric forms..

In order to accomplish a classification of stereometic forms we used the prepositional calculus with operations already known from Boolean algebra. Each proposition is an affirmation or negation of the presence of a certaion feature which an object could possess. A certain combination of propositions gives a mathematical model of a spacial form. This procedure make it possible to use the computer in the pracess of the classification and recognition of spacial patterns. If the concept of the object corresponds to that of the abstract model. The answer should be satisfactory.

Obviously, it is not necessary to take into account all established propositions, bux only characteristic ones, because complete classification hopeless if all possible inputs are considered. However., classification carried out in phases.— A, B are classified in phase I, and C, D in phase II — and manifests a large economy as regards the complete classificatory system.

As an example, a choice tree is given, as shown in Fig. 4; it consists of a series of phases by means of which one gradually arrives at more precise identification.

In the decision process, we start with the assembly of initial propositions, which form the basis of the calculus, marked with:

$$L = / L_1, L_2, \dots , L_n /$$

From n element s ot the base L, we can theoretically form 2 members of all possible combinations as follows:

$$S(L)=L_1.L_2...L_n+L_1.\bar{L}_n+...+\bar{L}_1.\bar{L}_2...\bar{L}_n$$

(The sign over the letter means negation)

If some basic propositions are joined by logical connections, the disjunction s(L) will have some empty membes (the values of which are zero). In this case, the number of conjunctions is reduced to 2 - k, where k is the number of eliminated conjunctions. As k becomes bigger, the logical connection between basic propositions becomes stronger. The remaining conjunctions form the reduced disjunction r(L) which characterizes one determined object, i.e., a mathematical model which can easily be represented by a string of numbers.

Logical connections between the propositions L_i could be carried out in different ways.

Here we have used the form of equality, which, within certain limits, can be treated as an equation and processed numerically on the computer.

As an example, here is a group of characeristic propositions with the marked phases of classification mentioned before:

I A There is contact with the object.
II B Surface is curved.
C Surface is plane.
III D "Vertical" edges are parallel.
E "Vertical" edges connect at one point.
JV F Three pairs of parallel surfaces exist.
V G Distances between neighbouring vertices are equal.
..........etc.

This group is not definite, it can be changed and enlarged, depending on the principal task of classification.

Combinations of propositions existing in the description of the object do not exhaust all theoretical possibilities. Besides conclusions of logical connections between propositions which allow us to distinguish between objects, it is also possible to find common conditions for the variants in one class of objects.

Considering the disjunction chracteristics described above, the logical connection for a cube, using the equality form, would be:

r(L) - A. B. C. D. E. F. G

giving, as a result, a new proposition:

L : Body is a cube

or

L = A . B. C. D. E. F. G

Because the density of the sensors is low, the model obtained is more or less approximate. In the beginning, we limited our exploration to simple objects with plane surfaces.

Input date have to be obtained by scanning the object. Any touch of the object by the sensors corresponds to one plane; the equation of this is easy to find using analytic geometry. In this way, the touched body will be represented by one polyhedron which envelops the body and wkich is composed of the group of planes' whose equations are known. Co-ordinates of the vertices and equations of the edges are easy to calculate. (The equation of the support plane is the same as the equation of the supported surface of the polyhedron).

If we suppose that an object is touched at point p (determined by the vector r_1) by the sensor s (determined by the unit vector $\bar{r}$), then the equation of the tangential plane is:

$$(\bar{r} - \bar{r}_1) \cdot \bar{r}_o = o$$

Then, if the object is scanned by touching in more points, we can have the assembly of all equations of the surfaces of the enveloped polyhedron, which gives us the mathematical model of the object.

A flow chart of stereometric forms using tactile information Is shown in Fig. 5. In the flow chart an input matrix is obtained by tactile exploration of the object, measuring the co-ordinates of the touch points and the two angles which determine the tangential plane in each point, using a convenient reference system. The first three numbers in one row are Cartesian co-ordinates: x, y, and z respectively, and the following two are values of the azimuth and inclination angles. In this way the matrix has five columns and as many rows as there are touch points with different tangential planes.

In the present stage of the work the number and equations of tangential planes which determine enveloping polyhedron are computed, then the angles between planes and the locations of the polyhedron's vertices as intersection points of three or more planes. The results from these computations could be considered a mathematical model of the object. Then the program identifies perpendicularity and parallelism between planes, if any exist. Having all these results, the program confronts them with basic propositions, which could be assumed as the logical model of the object.

The second part of the program, which is realized only in principle but so far not yet written in computer language., provides, on the basis of confronting real and theoretical disjunctions, and by the use of baaic propositional calculus, to obtain logical connections between basic propositions, with regard-to the created object and to make decisions about the geometry of the object.

Experimental Model

In the first step of an experimental study, tactile information is taken by one finger with four sensors which are perpendicular t6 each other, as shown in Fig.6. The finger is able to keep in contact with the surface of an object, moving along it.

The finger consists of a rigid support terminated with a semisphere. On the surface of the semisphere, a number of small-pressure sensitive on-off sensors will be distributed, according to geometrical criteria; however, this experimental finger is only distributed with four sensors, still according to geometrical criteria. A set of motors driven by electronic logic moves the finger in the space. The orientation of the finger remains unchanged with respect to the three chosen axes: x,y,and z.

The surface equation is determined by the position of the finger, when the sensor is in contact with the surface which delimits the object and by the identification of the sensor concerned.

If the finger is able to move, keeping in contact with the surface which delimits the object, it is possible to obtain the group of equations of the surfaces whose envelope approximates the shape of the object.

The block scheme of the electronic logic, which commands the control system of the finger, is shown in Fig.7. The scheme shows the electronic concerning only one sensor for movements of the finger on the x and y surface. The electronic circuit is similar for all the sensors.

In Fig.7, a generoc sensor is symbolized by the switch S . S is closed, when the i-th sensor is in contact with the object, and the finger moves along the object according to the predetermined direction of the switch S . That is, a signal proceeds to block A, the essential element of which is an SCR. The voltage V , at the output of A, goes to the block B which controls the motors M_x and M_y in order to move the finger in the direction dj associated with the sensor S . Let us suppose that the sensor loses its contact owing to the S being opened. The block is such that V is still present, to try to make new contact. We permit the finger to move the same direction di up to the maximum constant length: then we impose a movement towards the direction perpendicular to d , up to the maximum contant length if there is no contact; the following movement is imposed towards the direction, perpendicular to the last one, until the switch makes contact with the object.

The movements of the 4-sensored finger are illustrated in Fig.8, and the following will happen:

1) contact is restored during dr.

2) contact is restored at any moment during the cycle.

3) contact is not restored after the cycle

has been completed.

Fig. 9 shows the contour made by the 4-sensored finger exploring the object. Thick lines represent the contour of the object when the switch is closed, and the fine lines the cycle as shown in Fig.8. *The* points indicated by x are the contact-points on the surface of the object. We can draw one contour line (thick line), if we provide an appropriate angled sensor on the finger. We are also considering using a ball with tactile sensors instead of the finger to recognize a surface in the same plane of the object.

Concluding Remarks

In this paper, we have discussed conceptu*-ally the principles of a visual-tactile symbiotic system combining stereometric pattern recognition with tactile perception involving one finger with 4 sensors- However, in computer simulation, we considered only the tactile perception of grasping with two fingers and provided that the two tangential planes at the point of contact of the fingers with the object are almost parallel. For this purpose a terminal device with two fingers articulated in the proportions of the human hand has been partly realized.

In realizations of the symbiotic system, in order to incorporate the results of tactile perception discussed here, we can start by arranging the explored area in a more convenient way, particularly adapted to the optical part of the system. We can divided this area with horizontal planes distant one from the other for increment $\Delta z = 1$. In our reference system equations of these planes will be:

$$z = i, \quad (i = 0, 1, 2, \ldots, L)$$

If we remember that the general equation for tangential planes determining the envelope of a polyhedron is:

$$F_k(x,y,z) - 0, \quad (k = 1, 2, \ldots, n)$$

then the common solution for both equations will be:

$$F_k(x,y,i) = 0$$

i.e., in explicit form:

$$y_k - y_k(x,i)$$

which will adjust the analytical expression for intersecting lines between tangential planes and sets of parallel z-planes. If we form quadratic martices in these z-planes, and put L along intersection lines and 0 on rest, we will have some kind of binary digitalized contour representation. Now we can uniformly consider optical and tactile information.

In the tactile model, the sequence of switches is an important for recognizing objects, in order to determine the directions of the finger's movements as shown in Fig. 8. If and only if in z-plane, the sequence of the switches should be ordered counter-clockwise as S , S , then continuously S_1-, S_2-,......, $S_{n/2}$— n/2
where, n is numbers of switches in the same plane, and each switch provides the same angle on the surface of a finger.

From this introductory research, it is possible to point out that the visual-tactile symbiotic system is more practical and efficient for stereometric pattern recognitions than the use of conventional methods.

Acknowlegements

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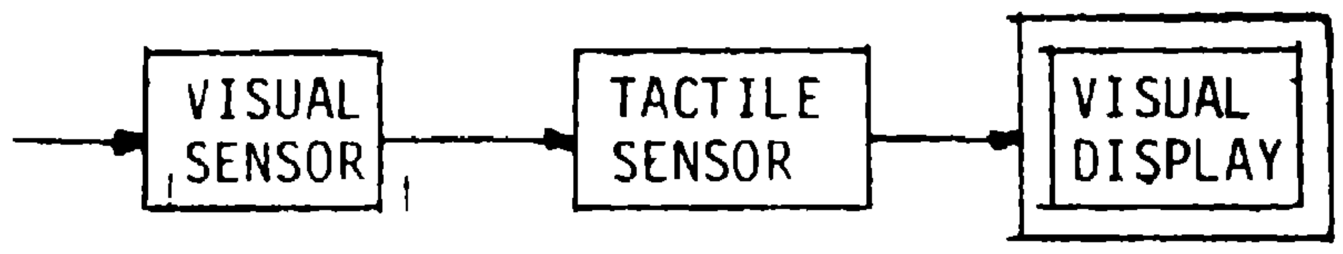
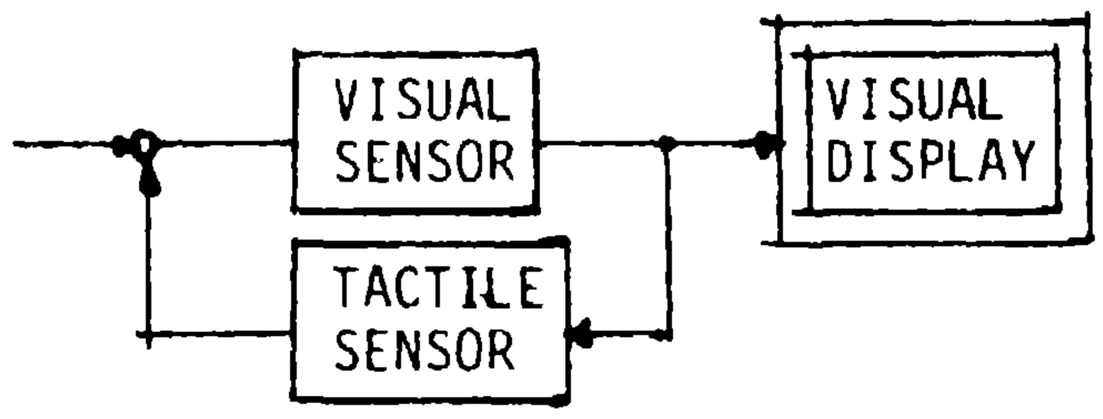


(a) Open-loop structure



(b) Closed-loop structure

Fig. 1 Structures of visual-tactile symbiotic system

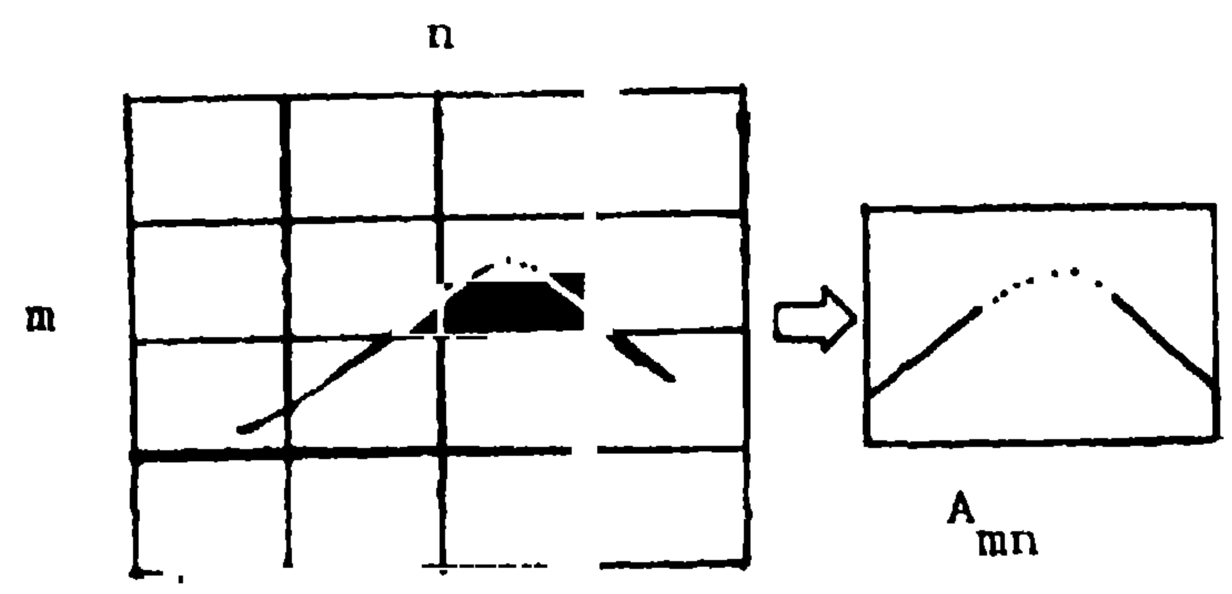


Fig. 3 Divided scene p(u,v).

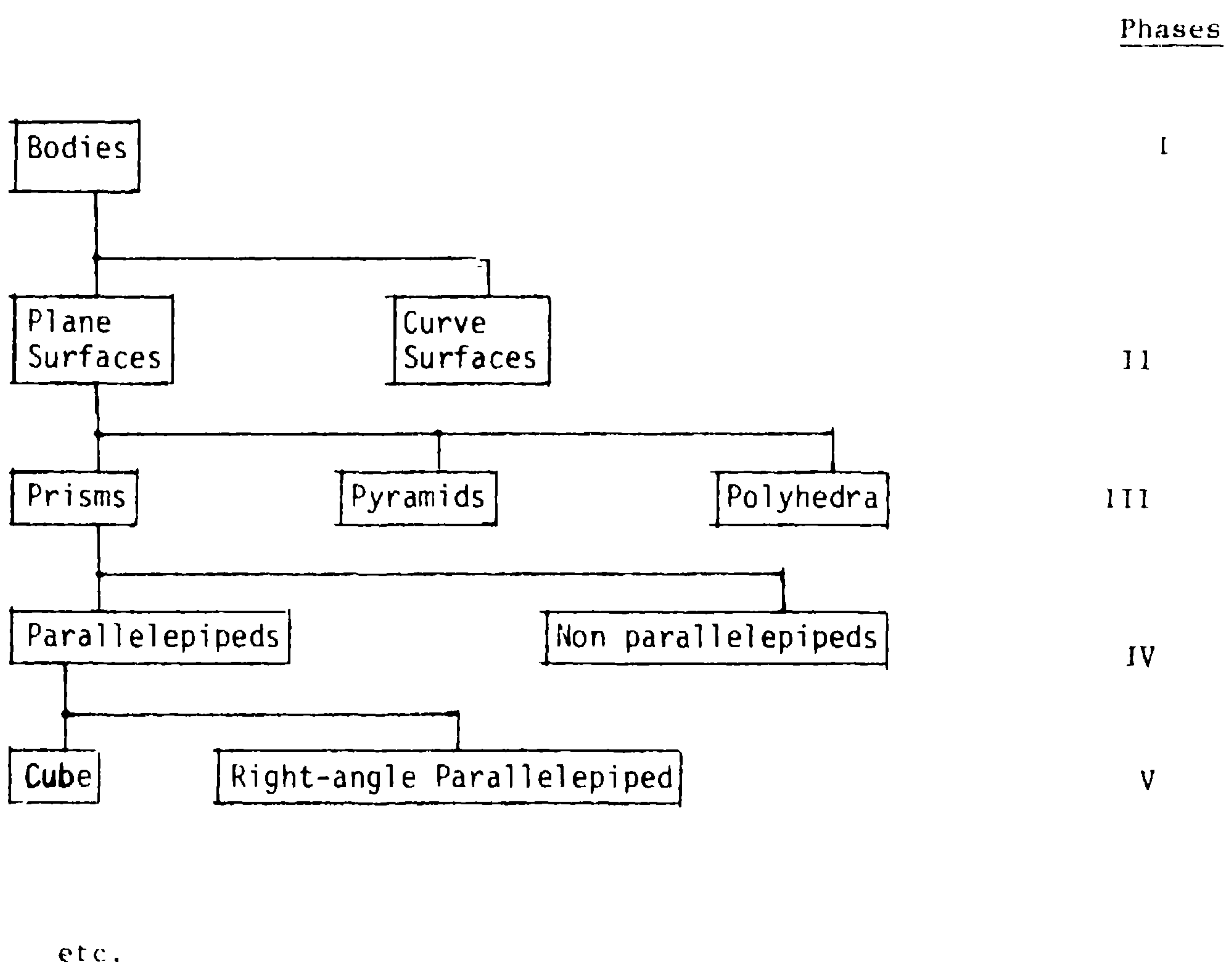
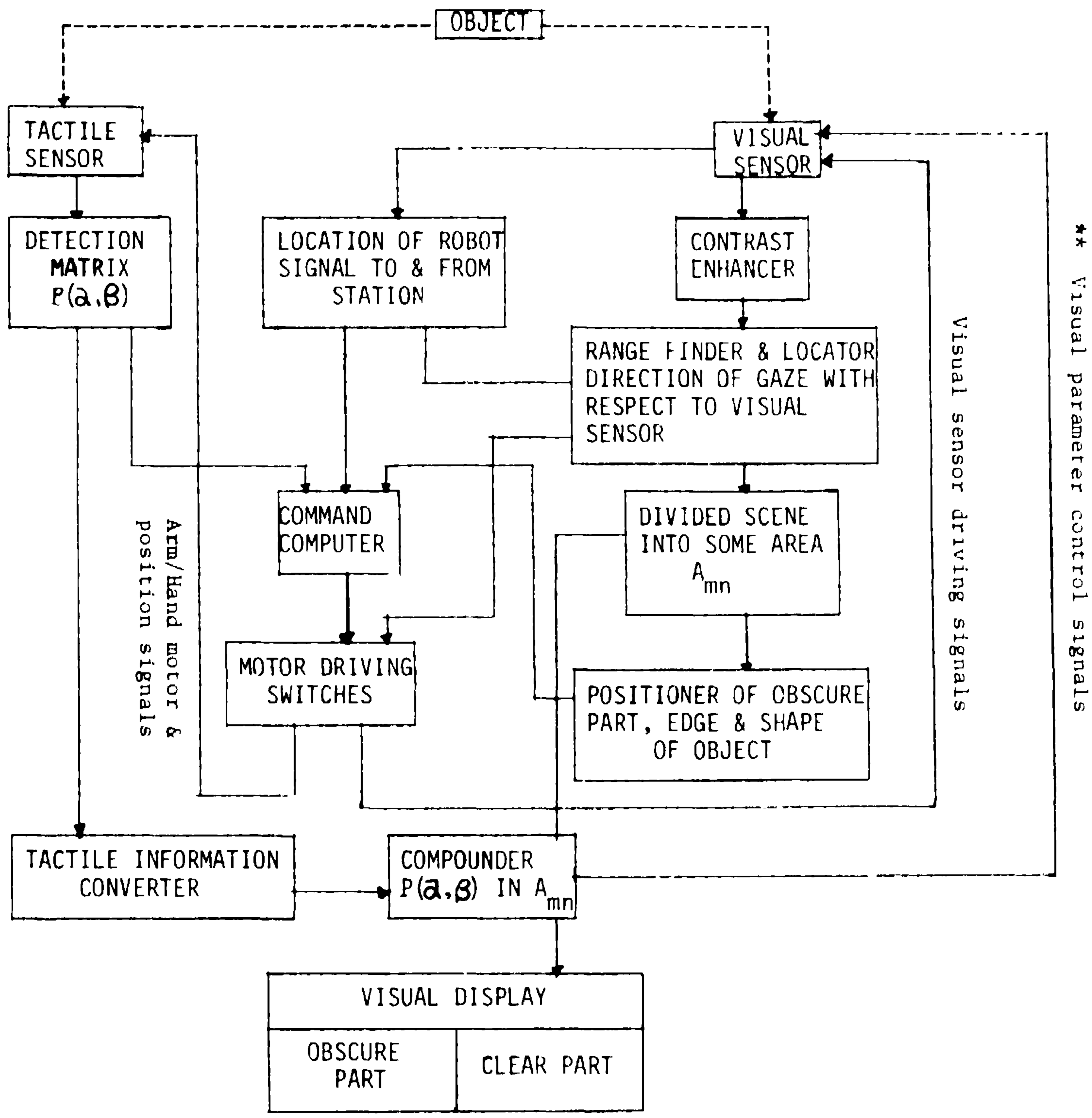


Fig. 4 Choice tree



** In the case of closed-loop symbiotic system

Fig. 2 Block diagram of visual-tactile symbiotic system.

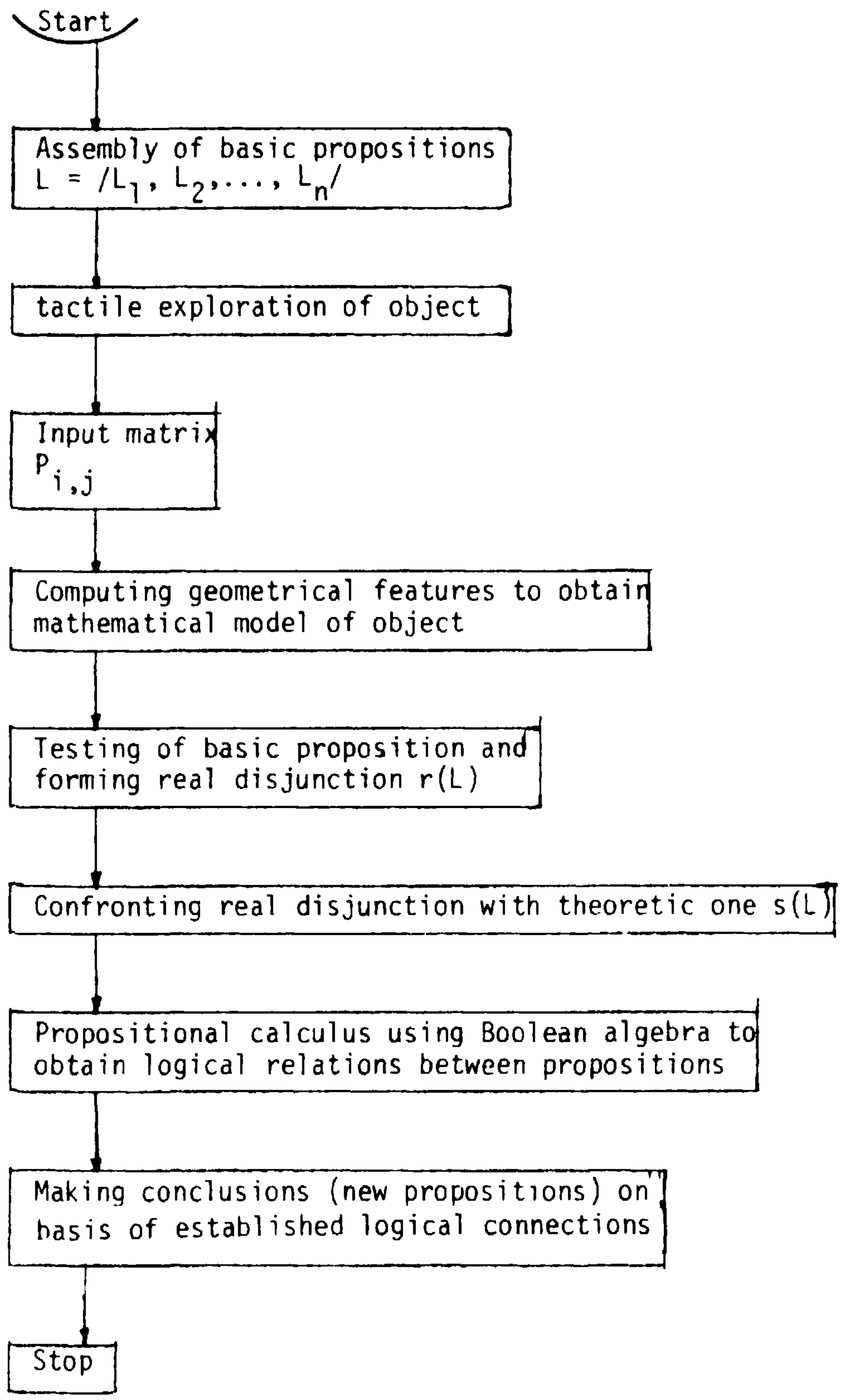
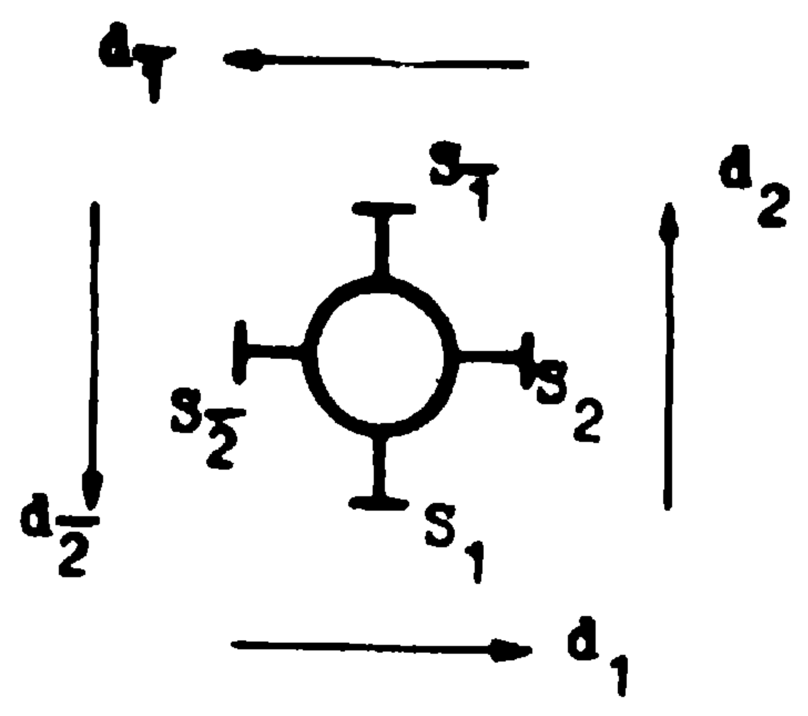
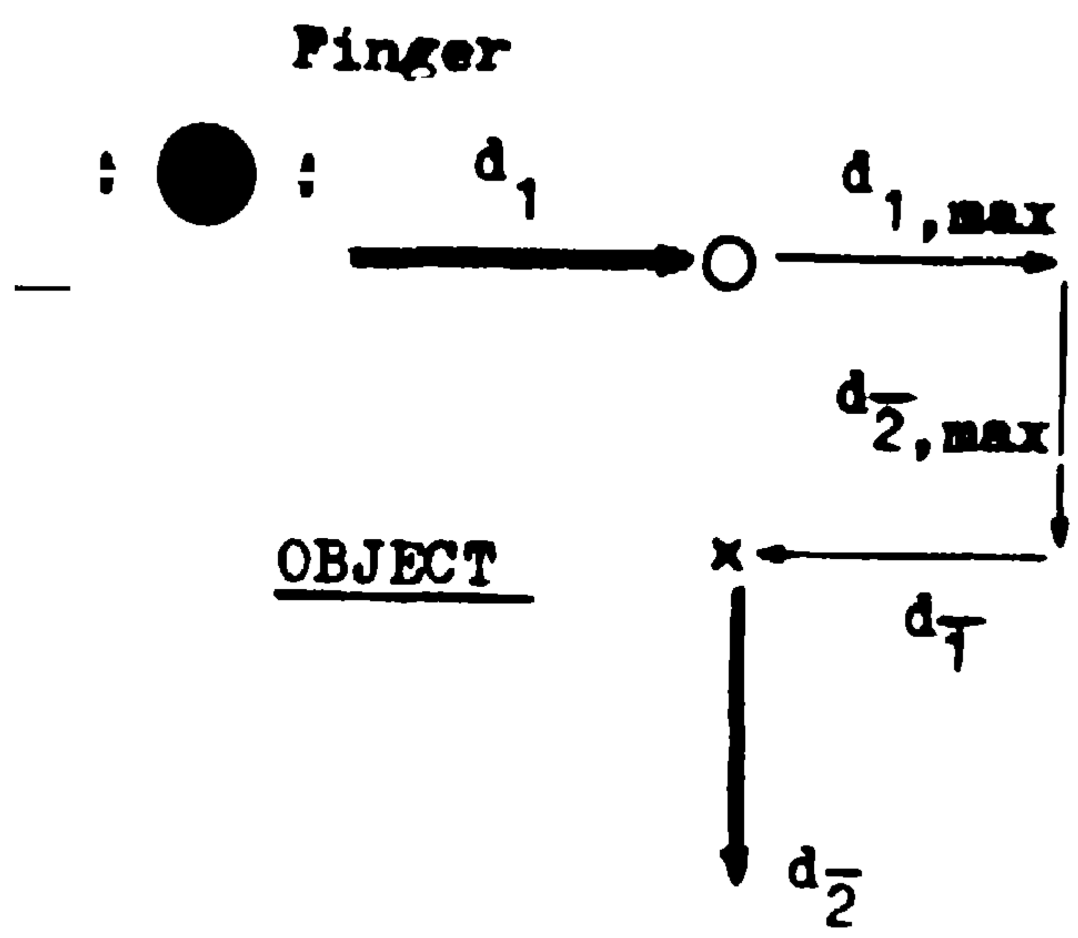


Fig. 5 Diagram of computer program for eleboration of stereometric forms using tactile information



Numbering of switches and orientations of movements, each switch moves in pre-determined direction as shown in arrows.

Fig. 6 4-sensored finger and its movements



d_1 : movement of direction d1 whiie switch S1 is closed.

$d_{1,max}$ the maximum constant length of direction d1 while switch S1 is opened.

$d_{\bar{2},max}$: the maximum constant length of direction d_2- while switch S_2 is opened.

$d_{\bar{1}}$: movement of direction d_1- while switch Sr is opened; such movement should be continued until switch S_1 is closed or the system is stopped-

Cycle : $d_{1,max}$ ——— $d_{\bar{2},max}$ ——— $d_{\bar{1}}$ in this case.

Fig. 8 Movements of 4-sensored finger.

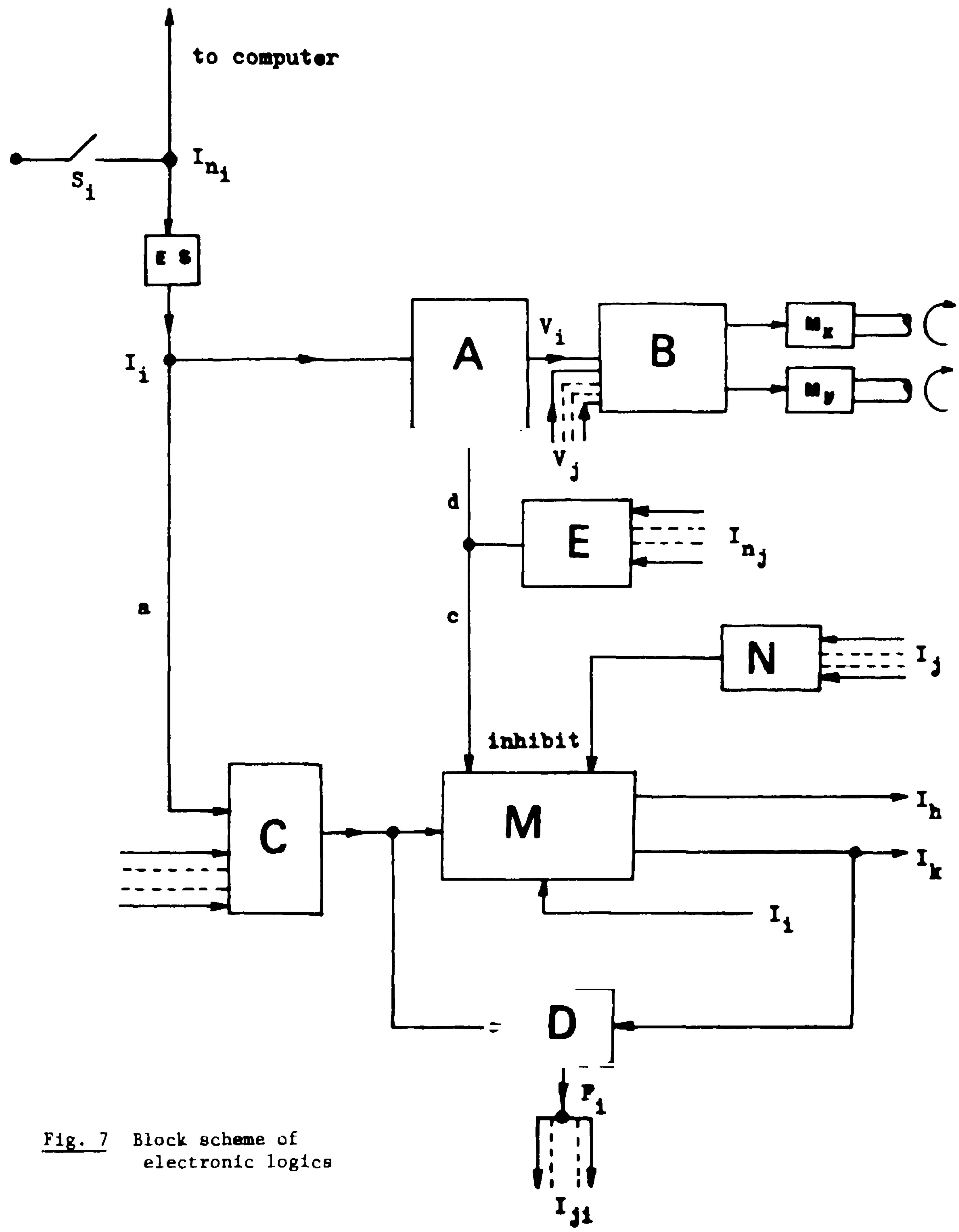


Fig. 7 Block scheme of electronic logics

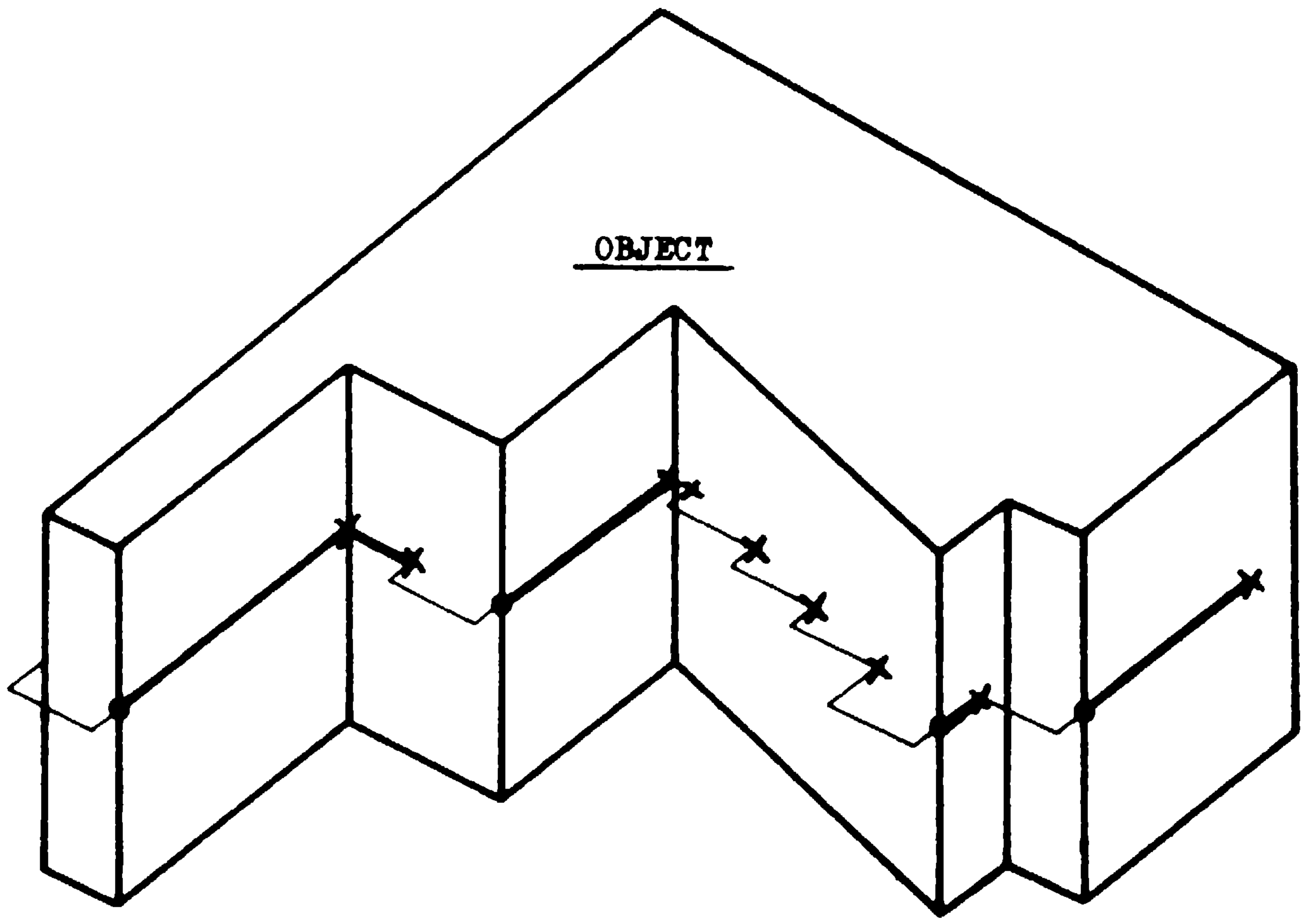


Fig. 9 Contour line by 4-sensored finger.