ARTIFICAL TACTILE PERCEPTION WITH COMPUTER PROCESSING

N.S. Ivančević and L. Cordella

Summary

An artificial touch perception system has been developed in order to study a method of processing information that can be obtained through tactile exploration of three-dimensional formes. The results can be useful for many purposes.

The first part of the work concerns the project and realization of the tactile explorator. For this purpose we used some kind of artificial limb like a finger with a certain number of touch sensitive transducers distributed along the surface of the finger tip. The information received by touching the object with the finger is successively utilized as the input of the control servosystem which moves the finger point by point along the object surface, in order to proceed with the exploration of the examined object.

The second part describes the use of the propositional calculus in logical classification of the objects, as a method of 3-D pattern recognition.

Elaboration of the input data (obtained by tactile exploration) and computation of characteristic geometrical features of 3-D forms has been preformed with a computer.

Introduction

In the field of artifical limbs control, not only the mechanical but also the sensing function is important. They are both closely connected in the feed-back control system. In human beings the sensing function of upper limbs is the sense of touch. The nerve endings of this touch sense are destributed on the limb periphery in a spatially changeable geometry.

It is clear that visual control has the dominant, but not absolute, role in manipulation and perception of threedimensional objects by human beings. How large a part tactile sense plays, it is difficult to say, but it cannot be neglected.

For correct manipulation of objects, it is necessary to know their spatial characteristics, such as shape and position. Before direct contact with the object, when visual sense plays an exclusive role, decision (depending on the principal task) is based only on the optical information. At the moment of touch, both optical and tacticle information bedin to flow, resulting in inter-

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correlation. From this moment, visual sense can be partly released for other tasks, and tactile sense can take over to pick up information about the object.

We began with an analysis of the role of touch in perceptive processes and in the handling the objects by human beings. Our aim was the formulation and experimentation of electromechanical models of upper limbs able to operate by utilizing information which they themselves can procure about the surrounding world.

As out nearer goal, we are trying to optimize the prehension of objects, depending upon their three-dimensional form, at a lower level in the hierarchy of manipulation control.

A higher level of control hierarchy is the task to be carried out by manipulation. For example, this task can be: "grasping", "lifting", "movement", etc., but as the number of such tasks can be very large, it is not easy to attempt the generalization of prehension and manipulation principles.

Let us consider the pick-up and processing of tacticle-spatial information. The work programme is composed of two parts: the first part foresees the project and realization of a limb capable of exploring three-dimensional patterns by touch. In this phase the obtained information is utilized as an "input" of the limb's control system to proceed with the automatic exploration of the considered pattern.

In the second part, the information stored during exploration is interpreted and utilized for the desired aims. As an example, we can quote several kinds of utilization:

a) As an "input" of the limb's control system to allow a better positioning during manipulation, depending upon the shape of the object.

b) Classification of three-dimensional forms.

c) To improve the informative content of poor quality optical images of objects.

Tactile Exploration

As far as the first part is concerned, the servo-system, which allows a limb to explore an object by touch, has been developed and is now being tested.

By "exlopring" we mean the limb's ability, once in contact with the object, to move along its surfaces, utilizing for this purpose, the information which it is gradually able to pick up.

At our present stage of research, the term "limb" implies a device furnished with a "finger" and "pincers"; the finger is equipped with sensors, the pincers have the unique function of object grasping. Grasping is based on the simple principle of minimal angle of prehension; that is,when the two tangential planes at the points of contact between the two fingers of the pincers and the object are essentally parallel. Moreover, the grasping points should be in line with the object's center of mass. The device is moved in space by three motors M_x, M_y, and M_z. The sensors are of the On-Off kind, sensitive to pressure and distributed along the semispherical surface ofthe finger's terminal part at the cross-points of meridians and parallels.

Let us assume the finger moves translatorily with respect to the chosen Cartesian reference system x, y, z. If a particular sensor is on, then the finger is in contact with a surface whose tangential plane at the point of contact has a determined orientation.

In a prototype under study, 33 sensors are distributed on the surface of the finger tip. This permits us to distinguish between plane surfaces at a 30° slope from each other.

In a second prototype now being tested and intended for the exploration of objects composed of rectangular parallelopipeds, only four sensors located 90° from fech other along the equator of the semispherical finger tip have been used.

In each case, a relation is obtained between families of space surfaces (intended as delineating the objects) and points of the semispherical finger tip (or rather sensors distributed thereon).

Let us limit ourselves to the case where the object under examination is composed of rectangular parallelopipeds and the exploratory finger is furnished with four sensors arranged as in Figure 1.

Let us suppose that the finger moves in a direction toward the object. At a certain point sensor S_3 comes into contact with surface P_1 which delimits the object.

If the object is at rest within the chosen coordinate system, it is possible to measure immediately the coordinates of the contact point. Since every sensor is associated with a family of parallel planes of the space, we can also measure the two angles

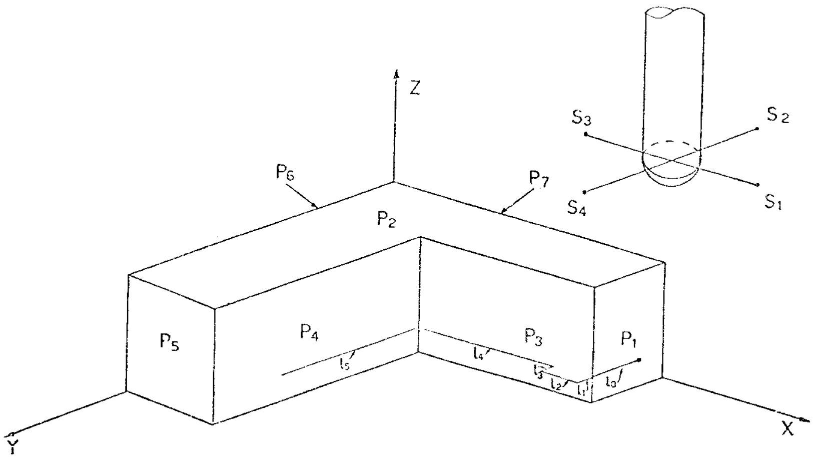

Fig. 1. Example of tactile exploration.

(in a spherical coordinate system) identifying this family. All these data, transmitted to a computer, allow it to calculate the equation of plane P_1 in the reference system. Once the first contact with an object has been established, the finger must be able to move along the contour of the object to obtain the equations of the surfaces delineating it. Thus, when a sensor indicates that contact has occurred, appropriate voltages are sent to the motors to move the exploratory finger along a plane tangential to the point of contact in a direction parallel to the x-y plane with a chosen sense. Therefore, to each sensor is associated a direction of movement. In the case of the example, the course imposed is l_o. The abovementioned voltages are present only while contact exists. In our example, contact is lost for the first time at the end of course l_o. When the sensor passes from state ON to state OFF (loss of contact), in order to establish a new contact, the finger continues to move for a length l_1 in the direction previously followed and thereafter for a search length l_2 in an orthogonal direction. If it does not meet the object again, it continues for a search length l_3 in a direction orthogonal to l_2. If contact is re-established, during the described cycle, the finger moves in the direction imposed by the contact itself. If the cycle terminates without recontacting the object, exploration ends with the decision that the object has at least one dimension inferior to the search length l_2. Exploration can eventually continue in different planes.

In the present example, while passing along the course l_3, sensor S_2 comes into contact with plane P_3. The finger, then moves along the course l_4 until contact between S_2 and P_4 is established, although contact between S_2 and P_3 is continued.

In order that the finger may follow the last surface it has encountered to continue exploration, it can be made so that each sensor in the passage from state OFF to state ON inhibits the dispatch to the motors of voltages, due to every ON-sensor except itself. The finger can thus move along l_5 and therefore continue exploration by successively touching P_5, P_6 and P_7. It then returns along P_1, but as soon as contact S_3 - P_1 is established for the second time, the finger is moved in the direction of the z-axis for a fixed length and in this new plane z=const., further exploration of the object is accomplished. The z-increments end when, after a certain increment, contact is no longer maintained with the object.

In the case of objects of complex shape, the employment of a greater number of sensors than the four used in the example, allow us to obtain, after an exploration such as that described above, sufficient data to calculate the equations of the planes whose envelope approximates the shape of the object under examination. The degree of approximation is a function of the number of sensors employed.

A block diagram of the electronics relative to a sensor capable of the said logic is given in Figure 2.

A generic sensor is symbolized in the scheme by the switch S_i. Other switches are labelled by indexes h, j, k, etc. When the i-th sensor is in contact with an object, S_i closes sending a signal to the block A. The voltage V_i at the output of A goes to the elaboration and amplification block B, which injects to the motors M_x and M_y two voltages, so as to move the finger towards the direction associated with the sensor S_i.

When the sensor loses contact, S_i opens. The cycle necessary to establish a new contact, as previously described, is performed by the three gated monostable multivibrators M_1, M_2, M_3.

The blocks D and C inhibit the starting of spurious cycles at the end of length l_2 and l_3.

The block N establishes whether one or more sensors, except S_i, are closed. In the affirmative case, Gate 1 inhibits the starting of the cycle associated with S_i.

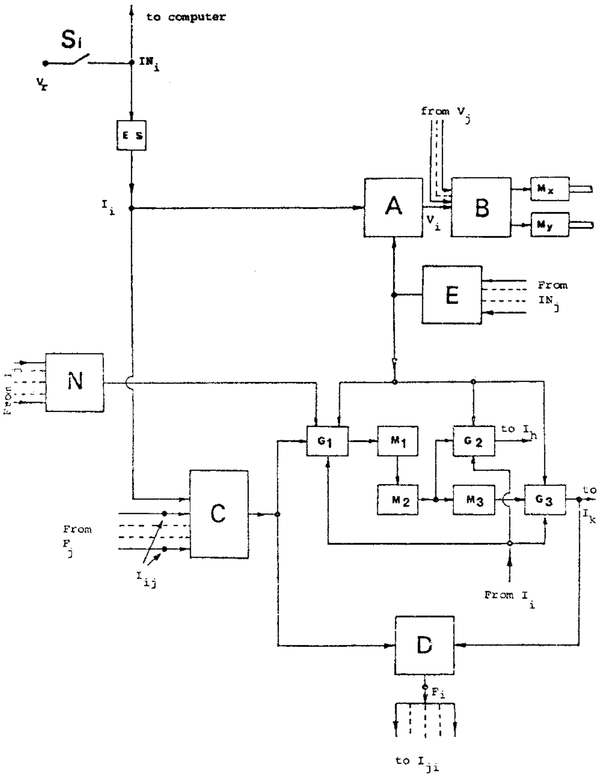

Fig. 2. Block scheme of control electronics.

The block E allows the finger to always move towards the direction imposed by the last sensor that closes, even if other sensors are still closed. Also the block E, through the gates 1, 2 and 3, stops the cycle when contact is restored during the cycle itself.

Elaboration of 3-D Forms

The information obtained during tactile exploration may now be used for recording the geometrical features essential for the construction of the mathematical model which symbolizes the object in the form of an assembly of certain characteristic elements. Such a symbolic model has to be used by the computer to acheive the desired goals.

For example, a method for the classification of 3-D forms is presented here. We use proposition calculus with operations already known from Boolean algebra. Each proposition is an affirmation or negation of the presence of a certain feature that an object could posses. A certain combination of propositions gives the logical model of the object. This allows us to use the computer in the process of classification and recognition of spatial pattern.

Obviously it is not necessary to take into account all established propositions, but only characteristic ones, because complete classification is hopeless if all possible inputs are taken. However, classification carried out in phases (for example, some features A and B are classified in phase I, and C and D in phase II, etc.), manifests great economy as regards the complete classificatory system.

As an example, a choice tree is given consisting of several phases by means of which more precise geometrical identification can be obtained gradually (Fig. 3).

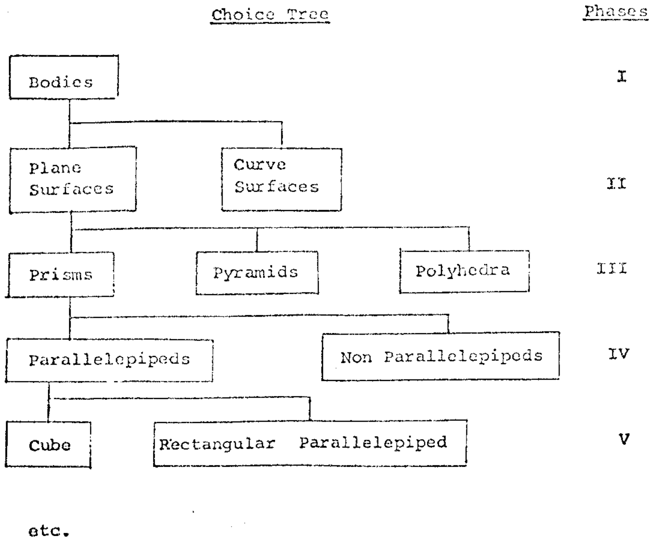

Fig. 3. Choice tree.

The basic assumption is the proposition telling us that some feature is present. Individual objects are described as assemblies of corresponding features whose presence is affirmed or negated by tactile exploration and computer calculation.

The object is described in terms of logical conjunction between propositions. By forming an association of propositions determining an object, we obtain the base of proposition calculus. Let the assembly of the basic propositions be:

$$L = /L_1,\ L_2,\ \dots\ ,\ L_n/ \qquad (1)$$

From the elements of base L, the disjunction of 2^n members of all possible conjunctions can be formed as follows:

$$s(L) = L_1 \cdot L_2 \cdot \dots \cdot L_n + L_1 \cdot L_2 \cdot \dots \cdot \bar{L}_n + \dots + \bar{L}_1 \cdot \bar{L}_2 \cdot \dots \cdot \bar{L}_n \qquad (2)$$

If some basic propositions are joined by logical connections, the disjunction s(L) will have some empty members. In this case, the number of conjunctions is reduced according to the strength of the logical connections: the stronger the logical connections, the smaller the number of the conjunctions. The remaining conjunctions form the reduced disjunction r(L), which characterizes one specific object and gives a mathematico-logical model which can easily be represented by a string of numbers.

Logical connections between 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.

An example is a group of characteristic propositions with the signed phases of classification mentioned before:

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

This group may not be definite, but it can be changed and enlarged, depending upon the principal task of classification.

Combinations of propositions existing in the description of the object do not exhaust all theoretical possibilities. Besides conclusions of the 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 as one example, the logical connections for a cube, the characteristic disjunction described above, using the equality form, would be:

$$r(L) = A.\ \bar{B}.\ C.\ D.\ \bar{E}.\ F.\ G. \qquad (3)$$

resulting in a new proposition:

L : object is cube (4)

or

$$L = A.\ \bar{B}.\ C.\ D.\ \bar{E}.\ F.\ G. \qquad (5)$$

Formal Apparatus

Because sensor density is low, the model obtained is more or less approximate depending on the complexity of the shape of the object. Initially we have limited our exploration to simple plane surfaced objects.

Input data has 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 determine using analytic geometry. In this way the touched body will be represented by one polyhedron which envelopes the body and is composed of the group of planes whose equations are known. Coordinates 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 polyhedron's supported surface).

If we suppose that an object is touched at point P (determined by vector $\bar{r}_1$) by sensor N (determined by the unit vector $\bar{r}_o$), then the equation of the tangential plane is:

$$(\bar{r} - \bar{r}_1) \cdot \bar{r}_o = 0 \qquad (6)$$

Then, if the object is scanned by being touched at more points, we can have the assembly of all surface equations of the enveloping polyhedron, which gives us the mathematical model of the object.

Computer calculations give other information, such as cross--selections, angles between planes, existence of parallelism and perpendicularity, etc., which form propositions for object identifications.

Here, it is possible to see how the aforementioned principle of the minimal angle of prehension can be used. Determination of the two parallel (or almost parallel) planes can give the decision of the way in which an object should be grasped.

As an illustration of the text, the flow chart of the computer program is attached (Fig. 4).

FLOW-CHART OF COMPUTER PROGRAM FOR DISTINGUISHING AND CLASSIFICATION OF PARALLELEPIPEDS USING TACTILE INFORMATION

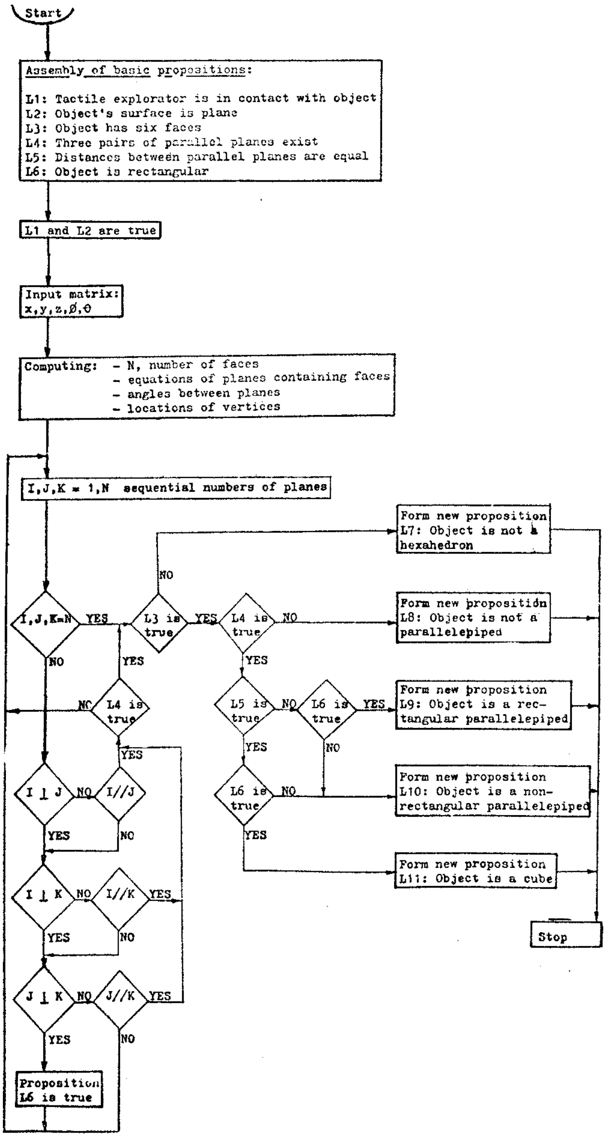

Fig. 4. Flow chart.

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END OF COMPILATION

// XEQ


OCTA-
  OBJECT IS NOT A HEXAHEDRON

CUBE1-
  OBJECT IS A CUBE

CUBE2-
  OBJECT IS A CUBE

TETRA-
  OBJECT IS NOT A HEXAHEDRON

PRAPAR-
  OBJECT IS A RECTANGULAR PARALLELEPIPED

KOPAR-
  OBJECT IS A NONRECTANGULAR PARALLELEPIPED

TETRA1-
  OBJECT IS NOT A HEXAHEDRON

TETRA2-
  OBJECT IS NOT A HEXAHEDRON

CUBE11-
  OBJECT IS A CUBE

CUBE22-
  OBJECT IS A CUBE

PRAPAR1-
  OBJECT IS A RECTANGULAR PARALLELEPIPED

KOPAR1-
  OBJECT IS A NONRECTANGULAR PARALLELEPIPED
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Fig. 5. Computer answers.

The answers of the computer for different objects, or different position of the same object, are shown in Figure 5.

Conclusion

In this work we have considered the use of some mathematico--logical methods for decision making in the field of artifical limbs control and three-dimensional object perception with computer processing. At the same time we have developed the hardware for a three-dimensional moving system, operated by servosystems and convenient electronics, for the handling of solid objects.

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