PATTERN RECOGNITION BY AN ARTIFICIAL TACTILE SENSE

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Abstruct

This paper proposes an artificial tactile pattern recognition system, which combines recognition by touching the object surface with an artificial tactile sense and recognition by grasping the object with an artificial hand.

The inspiration for this proposition was found in the function of the tactile sense of a human hand.

The fundermental principle of artificial tactile pattern recognition is to process a stress distribution that the unknown object produces in the artificial tactile sense elements.

In the proposed method, the 3-dimensional stress distribution is partitioned into a 2-dimensional peripheral pattern and a threshold decrement by analogy with threshold phenomena in the living body. The object surface is recognized as a sequence of the peripheral processings at each threshold decrement.

A simple experiment classifying cylinders and square pillars was performed by the artificial hand with on-off switches instead of the pressure sense elements. As the result, a high reliability of recognition is obtained.

1. Introduction

A manipulator system extending the function of the human hand has been carried out mainly for controlling nuclear " hot cells ". In this system, the perception of the handled objects is performed by the visual and tactile senses of an oparator. He can see the object, but the system requires a closed loop to feed back tactile sensory information to the oparator's hand. The operator senses only pressure which is given by the bilateral servo in the manipulator system. However, in this system an artificial hand is not being operated by machine, but by the operator. In contrast, the authors intend to develop a system for an artificial hand which is operated automatically by the machine.

In considering a system for an artificial hand or a manipulator system with artificial intelligence for handling the cubic objects, it is necessary that the system should have the functions to carry out the various mechanical operations automatically with respect to the results of recognition of the objects. Therefore, the device for operating an artificial hand should be considered as a single unit instead of as an operator plus the artificial senses.

Studies of the visual sense have been done not only in the field of physiology, but also in the field of the biological engineering. Consequently it seems reasonable the tactile sense also should be discussed from the standpoint of biological engineering and technological applications.

This paper proposes a scheme for pattern recognition using an artificial tactile sense and presents the experimental results of the pattern recognition of objects being gripped by an artificial hand.

2. Tactile Pattern Recognition using the VARISHOLD Method.

VAR1SHOLD Method is shortened form for a variable threshold method(1). The threshold is applied in a discrete time;its level is variable in each sampling time.

This section shows the method of pattern recognition using VARISHOLD Method which is considered as the modified IMICTRON(l). Several applications of the IM1CTR0N have already been discussed. The most distinguishing property of the IMICTRON is its time-varying threshold level with a function of reintegration, which makes it possible to realize a fuzzy logic, such as required for the dynamic visual-pattern-recognition network.

It is a matter of scientific knowledge that the physiological levels vary and that the living body has the properties of adaptation. The threshold is a reference level relative to external stimuli; its value changes due to circumstance. The VARISHOLD involves varying the threshold according to the parameters of the system as well as the input of the system. So to speak, this method constitutes the authors application of the variable threshold of living body to a technological context.

2.1 Artificial Tactile Pattern Recognition

In general, objects are recognized as a visual pattern. If pattern recognition with aid of the visual sense is skillfuly constructed, an artificial hand can be easily used as a manipulator for a general purpose machine or as the hand of a robot.

The following steps are considered to be the process of pattern recognition of an artificial hand with an artificial tactile sense.

1) Detecting quantitatively the size or form of the object from the sensing of the hand which is gripping the object.
2) Judging the state of the object surface by the artificial tactile sense.
3) Judging the state of the other surface by changing the grip state of hand.
4) Perceiving the object from the information of step 1) - step 3). The main discussion here is of the perception of the object surface state of step 2).

2.2 A Model of Tactile Receptor.

As shown in Fig.l, a simple model of tactile sense is derived from the physiological one. A rectangular box in the figure indicates the receptor of Fig.2. It is well known that the sensory nerve and its ending which governs the tactile sense exist in skin. The model ignores the functions of temperature, pain and touch and arranges a piezo-electric element or strain sensor corresponding to the pressure sense.

Until the collagen fibers become aligned in the direction of applied stress, the microscopic architecture of the collagen fibers in the dermis of skin is such as to allow a large deformation at very low stress.

Therefore, the authors consider the model in which the area surrounding a piezo-electric element is filled by semi-elastic material. When any object comes in contact with the surface of model, a strain resulting in elastic deformation of material induces and is converted to an electrical signal by a piezo-electric clement. Also, the Mach phenomenon which has the action of extracting the object edge feature occurs in skin similar to visual sense. The Mach phenomenon may be used in the processing of pattern.

2.3 A Realization of Receptor

It is well known that the physiological receptor corresponding to pressure sense is the Pacinian corpuscle emits impulses according to corpuscle deformation which results from the strain of skin tissue. The sensory nerve ending in a Pacinian corpuscle is surrounded by a lamellated fluid-filled capsule which is dependent on the viscous element. Then, an object pattern is able to be discriminated through the pressure pattern or stress distribution of a group of Pacinian corpuscles. Therefore, the receptor unit corresponds to Pacinian corpuscle described above and its unit input given as shown in Fig.2 can be considered as the surface of Pacinian corpuscle. As shown in Fig.2, the inner potential I of the receptor is compared with a given threshold G. If the inner potential I_p is greater than a threshold 0, the receptor output is given by a function generator. The inner potential I_p is an unknown factor, but it is able to determine a level on the basis of the threshold. In case of pressing globular surface against a surface of tactile sense, the stress distribution rasing in the receptive field corresponding to receptive group is shown in Fig. 3. Its distribution is a 3-dimensional one. The stress distribution is processed by the information for the each threshold. The authors consider the recognition of the surface shape of an object by the following method.

2.4 Recognition of the Pressure Distribution

From the result of the preceeding section, the pressure distribution due to the object is recognized by the VARISHOLD Method.

Let R be a region of the receptive field and let V(x,y,z) be the distribution of pressure in R, and R V(x,y,z) are a subset of 3-dimensional huelidean space E.

$$V \subset R \subset E$$

V(x,y,z) is supposed as a convex from the object shape. Moreover, the threshold distribution θ is considered as a plane.

Consider the intersection X_i between V(x,y,z) and P(θ).

$$X_i = V(x,y,z) \cap P(\theta_1) \qquad [1]$$

$$\text{for } i=1,2,3, \ldots\ldots, n$$

where θ_i is taken by the value for which X_1 is not an empty set.

P($\theta_{j=1}$)is given by a supporting hyperplane to V(x,y,z). Suppose that

$$P(\theta_1) = \theta_i \;,\; \Delta\theta_i = \theta_i - \theta_{i+1} \qquad [2]$$

V(x,y,z) may be described approximately,

$$V(x,y,z) = V_1 \oplus V_2 \oplus \ldots\ldots \oplus V_n \qquad [3]$$

$$V_i = X_i \otimes \Delta\theta_i \qquad [4]$$

where $\oplus$, $\otimes$ are a direct sum and a direct product respectively.

Therefore, as a boundary of X_i represents X_{Bi}, for each i, recognizing these 2-dimensional patterns X_{Bi} , that is , periphery pattern of V_i, 3-dimensional pattern V(x,y,z) is recognized by the following method.

Pattern V(x,y,z) is approximately given by the patterns X_{Bi} recognized in close succession.

Intersection $\tilde{X}$ between standard plane $\tilde{P}$ and V(x,y,z) may be defined as

$$\tilde{X} = V(x,y,z) \cap \tilde{P} \qquad [5]$$

where P =P(θ_i =δ), δ is a small value. $\tilde{P}$ and P(θ_i) are planes and parallel to each other.

Let us define a line $\tilde{l}$ parallel to z-axis and a line $\tilde{l}'$ parallel to $\tilde{l}$ through any point u_i of the set X_i on the 2-dimensional plane P(θ_i), and let u_i' be a point such that

$$u_i' = \tilde{l}'(u_i) \cap \tilde{P} \qquad [6]$$

Then, a parallel projection may be defined as

$$\prod_{\tilde{l}',\tilde{p}} (u_i) = u_i \qquad [7]$$

By thenarallel projection in the direction of the line 1, the elements in the pattern Xi are projected on the p. Xi' may be defined as

$$\prod_{\tilde{l},\tilde{p}} (X_i) = X_i' \qquad [8]$$

for i= 1,2, 3, ... ,n

A subscript i corresponds to the threshold θi and in the case of the subscript i = 1, the plane P($\theta_{i=1}$) is a supporting hyperplane of V(x,y,z).

Therefore, the parallel projection for each threshold θi satisfies the following relation, which shows the relationship between a mapped Xi' and X for the form of V(x,y,z).

1) Pillared form

$$X_1' = X_2' = X_3' = \ldots\ldots = X_n' = \tilde{X} \qquad [9]$$

A cylinder --- X_i' ; a circle for each subscript i.

A square pillar ---- X_i' ; a square for each subscript i.

2) Pyramidal form or spherical form

$$p = X_1' \subset X_2' \subset \ldots\ldots \subset X_n' \subset \tilde{X} \qquad [10]$$

A spherical form or circular cone ----------- X_i' ; a circle for each subscript i.

A pyramid --- X_i' ; a square for each subscript i.

3) Ridge or hip form

$$s = X_1' \subset X_2' \subset \ldots\ldots \subset X_n' \subset \tilde{X} \qquad [11]$$

A ridge form -- X_i' ; a square for each subscript i.

4) Frustum

$$w = X_1' \subset X_2' \subset \ldots\ldots \subset X_n' \subset \tilde{X} \qquad [12]$$

Frustum of a cone --- X_i' ; a circle for each subscript i.

Frustum of a pyramid ---- X_i' ; a square for each subscript i.

5) Plane

$$R = X_1' = X_2' = \ldots\ldots = X_n' = \tilde{X} \qquad [13]$$

where p,s and w are a point, a segment and a small closed plane, respectively.

From this classification, it is apparent that the overall pattern V(x,y,z) is recognized by the state of touch sensation in case of subscript i = 1.

A point of u_1, u_i and u on the line $\tilde{l}'$ may be described by an equation of a form similar to the equation [6],

$$u_1 = \tilde{l}'(u_i) \cap P(\theta_1) \qquad [14]$$

$$u_i = \tilde{l}'(u_i) \cap P(\theta_i) \qquad [15]$$

$$\tilde{u} = \tilde{l}'(u_i) \cap \tilde{P} \qquad [16]$$

and u_i is satisfied by the following equation

$$u_i = s_1 u_1 + s_2 \tilde{u} \qquad [17]$$

where $s = \overline{u_1\tilde{u}}$, $s_1 = \overline{u_1 u_i}/ s$, $s_2 = \overline{u_i\tilde{u}} /s$ and $s_1 + s_2 = 1$.

A cross-sectional pattern X_1, $\tilde{X}$ and X_i given by the threshold P(θ_1), $\tilde{P}$ and P(θ_i) are represented by $J_1(X_1)$, $\tilde{J}(\tilde{X})$ and $J_i(X_i)$, respectively. The relationship between the $J_1(X_1)$ $\tilde{J}(\tilde{X})$ and $J_i(X_i)$ is given by the following theorem.

Theorem

The following inequality for the $J_1(X_1)$, $\tilde{J}(\tilde{X})$ and $J_i(X_i)$ is established

$$J_i(X_i) \geq s_1 J_1(X_1) + s_2 \tilde{J}(\tilde{X}) \qquad [18]$$

the equal sign is valid for a case which V(x,y,z) is a pillar and frustum form.

Proof

Let W(x,y,z) be a solid figure of which the pattern is the pattern X_1 connected with the pattern $\tilde{X}$. W(x,y,z) is included in the V(x,y,z) which is a convex pattern. The pattern $\hat{X}_i$ may be defined as

$$\hat{X}_i = W(x,y,z) \cap P(\theta_i) \qquad [19]$$

$\hat{X}_i$ is included in the pattern X_i because of W(x,y,z) ⊂ V(x,y,z).

Therefore,

$$J_i(X_i) \geq J_i(\hat{X}_i) \qquad [20]$$

for W(x,y,z), the area corresponding to the pattern X_1, $\tilde{X}$ and $\hat{X}_i$ is given by Minkovsky's inequality.

$$J_i(\hat{X}_i) \geq s_1 J_1(X_1) + s_2 \tilde{J}(\tilde{X}) \qquad [21]$$

Then, the inequality [18] is shown by the inequality [20] and [21].

3. Pattern Recognition of the Grasped Object by the Artificial Hand".

Pattern recognition of the grasped object is carried out by the artificial hand with the tactile sense in an important factor for recognizing the surface shape of grasped object by the artificial hand. There are two distinct types of recognition for the grasped object by the artificial hand with the tactile sense. It is divided into two important properties of a method of recognition in which one type is to detect a point of contact with the surface of the object, another is to recognize the surface shape of the object as the information for recognizing the pattern of the grasped object surface by the artificial hand. In the each case, a possibility of detecting a coordinate of the artificial hand or finger must be included and the function of the artificial hand with the tactile sense is classified into 4 groups.

It is difficult that piezoelectric elements are closely arranged on the hand or the fingers as mentioned in the previous section. This section describes that the artificial hand as shown in Fig.4 grips the object and recognizes the object shape by means of the data, that is, the points of contact which are given by the artificial hand and the object.

A group of r-on-off switches, $x_1, x_2, \ldots x_r$ as the artificial tactile sense is arranged on the surface of the artificial hand or finger.

When the artificial hand grasps the object, the pattern of r-on-off switches, $x_1, x_2, \ldots\ldots, x_r$ is defined as $v(x_1, x_2, \ldots, x_r)$ which represents a point in a r-dimensional shape, which is associated $x_1, x_2, \ldots\ldots, x_r$ with the co-ordinate axis, respectively.

A set of the points in the space, $v_1(x_1, x_2, \ldots\ldots, x_r)$, $v_2(x_1, x_2, \ldots\ldots, x_r)$, $\ldots\ldots v_q(x_1, x_2, \ldots\ldots, x_r)$ is given by grasping the object many times. Then, the set of these points is classified by some categories which correspond to the pattern of the object. Let us define a hyperplane which classifies the set of these points, for example, point v_i belong to the category α, point v_j belong to the category β, that is,

$$(v_i - v_j) \cdot v + \frac{1}{2}|v_j|^2 - \frac{1}{2}|v_i|^2 = 0 \quad [22]$$

where A . B represents the inner product of A and B, |A| = A • A.

Therefore, the set belonging to the each category is classified by the same hyperplanes and the object is classified by the category which corresponds to the object.

3.1 An Lxperiment of Pattern Recognition by the Artificial Hand with the Tactile Sense.

The tactile sense as shown in Fig. 4 consists of 22 on-off switches arranged in order. A coefficient of the hyperplane equation is decided by grasping separately two kinds of object, a cylinder (90 mm in diameter) and a square pillar (70 mm in a side).

The artificial hand grasps each object 10 times and the pattern of on-off switch is given by $v_1(x_1, x_2, \ldots\ldots, x_{22})$, $v_2(x_1, x_2, \ldots\ldots, x_{22})$, $\ldots\ldots, v_{20}(x_1, x_2, \ldots\ldots, x_{22})$.

These hyperplanes for separating the cylinder and the squar pillar can be given and a coefficient of the following equation [23] can be made into table 1 ,

$$\sum_{i=1}^{22} a_i x_i - b = 0 \quad [23]$$

A position sign s. of v.($x_1, x_2, \ldots, x_{22}$) for each hyperplane may bedefmed as

$$\text{if} \quad \sum_{i=1}^{22} a_i x_i > b, \quad s_j = 1 \quad [24]$$

$$\text{if} \quad \sum_{i=1}^{22} a_i x_i \leq b, \quad s_j = 0 \quad [25]$$

A sign table is made into table 2. From the sign table, the hyperplane is eliminated by the method which lists up the representative point in the same subspace. Table 2 can be rewritten as table 3 (2).

It is clear from table 3 that row v„ can be eliminate from table 4 regardless of pattern classification, if v that is, s for the hyperplane I of pattern 2 and v , s. for the hyperplane 111 of pattern 2 have the value 1 or 0. Then, table 4 is given, and a block diagram of pattern classification is shown in Fig.S.

Experimental Results

The classification of the grasped object by the artificial hand is carried out automatically on the basis of a sequence consisting of search action, grasping action and action of classification.

Grasping action is carried out with the following steps as shown in Fig.d for processing the grasp uniformly.

- Step 1. The object is grasped by the thumb and the index finger.
- Step 2. The object is lifted by a wrist rotation.
- Step 3 The little finger grasps the object in addition.
- Step 4. The index finger is removed from the object.
- Step 5. The object is grasped by the thumb and fingers.

The experiment of the classification is carried out by using the objects of the cylinder and the square pillar including the one which is used for deciding the coefficient of the hyperplane.

Table 5 shows the object type which is used for the experiment. The number of times, and the square pillar is grasped by the state which is slightly rotated on its axis. As the experimental results, a percentage of correct answers for the classification is tabulated in table 5.

It is evident that the percentage of correct answer is over 90 percent for a neighbourhood of the object, C3 and S3 which is used for deciding the coefficient of hyperplane. The result of the experiment may be applied to the recognition of the objec' by adjusting the finger length in case of limited objects.

4. Conclusion

A method of pattern recognition has been discussed which uses an artificial tactile model which has been compared to a physiological model of skin.

It is shown that recognition of its shape over the surface of the solid object can be easily carried out by the artificial tactile sense,rather than by the artificial visual sense and also that the artificial tactile sense can be used as an supplementary method for processing of the artificial visual sense. The relationship of the area of patterns for each threshold is given.

Moreover, the method and some experiments for recognizing the grasped object are given. A simple experiment classifying the cylinders and the square pillars is performed by the artificial hand with on-off switches instead of the elements of the artificial tactile sense.

Experimental results show a high probability of recognition.

5. Acknowledgement

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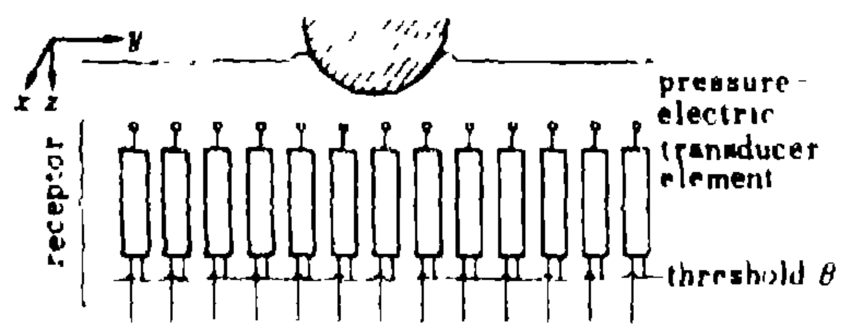


Fig.1 A schematic diagram of the tactile model.

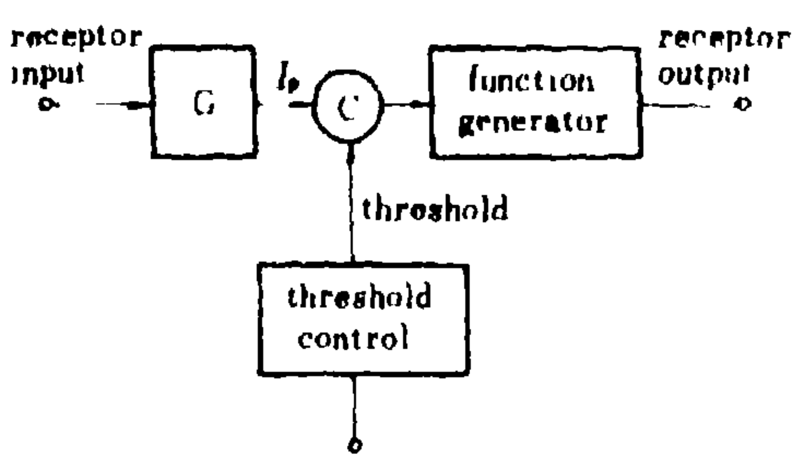


Fig.2 A schematic diagram of the tactile receptor.

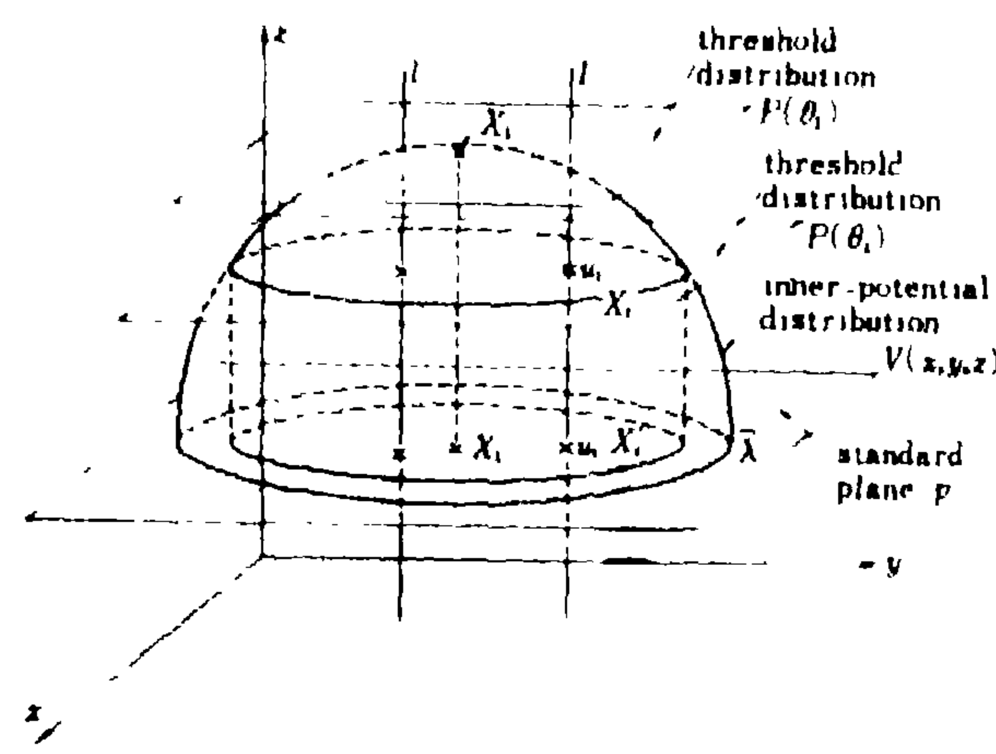
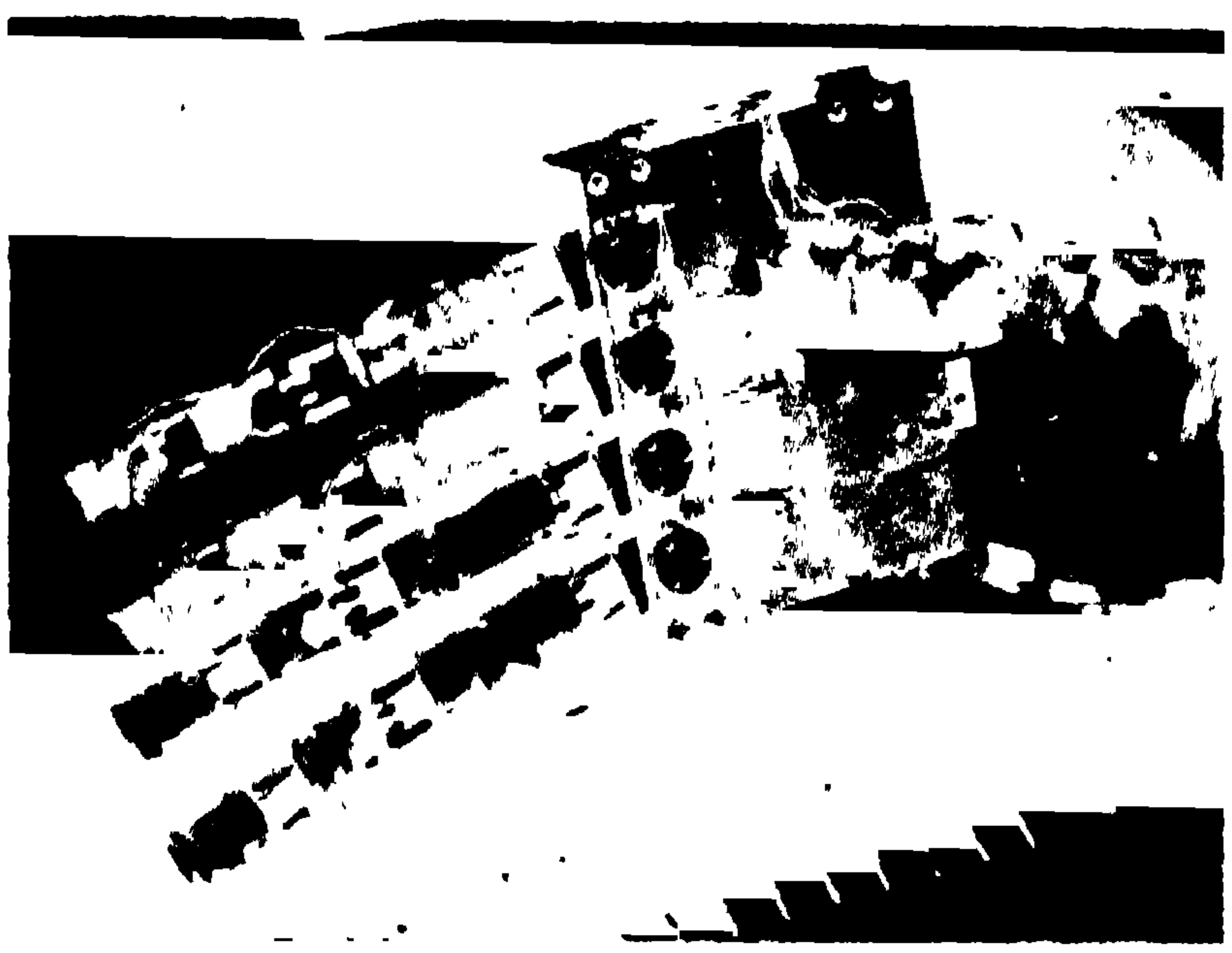
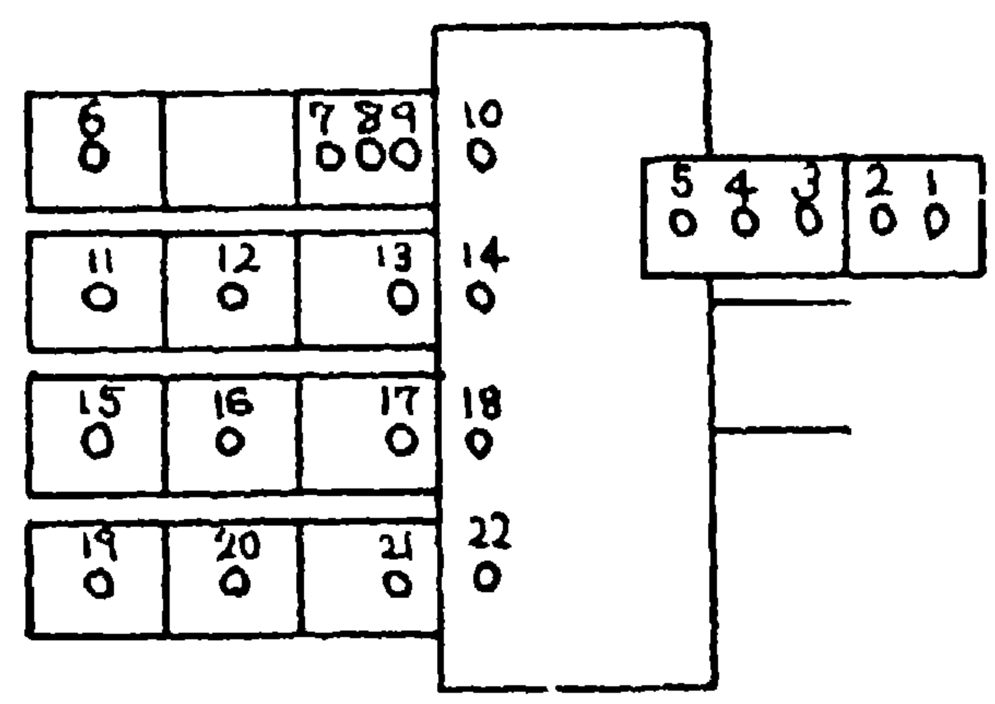


Fig.3 A pattern classification by using the parallel projection.





o : Position and its number of on-off switches.

Fig.4 Photograph of artificial hand and a position of the tactile sense.

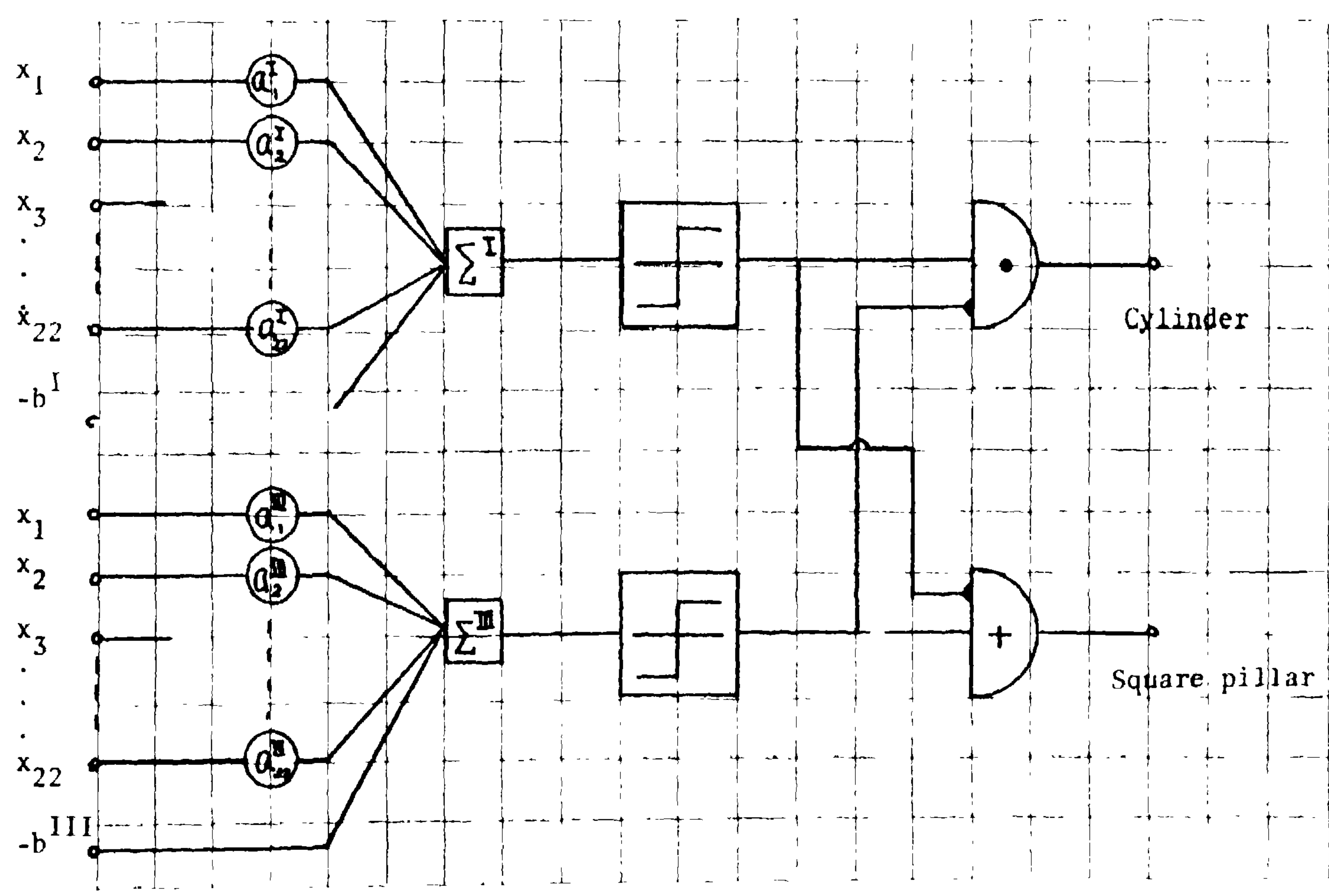
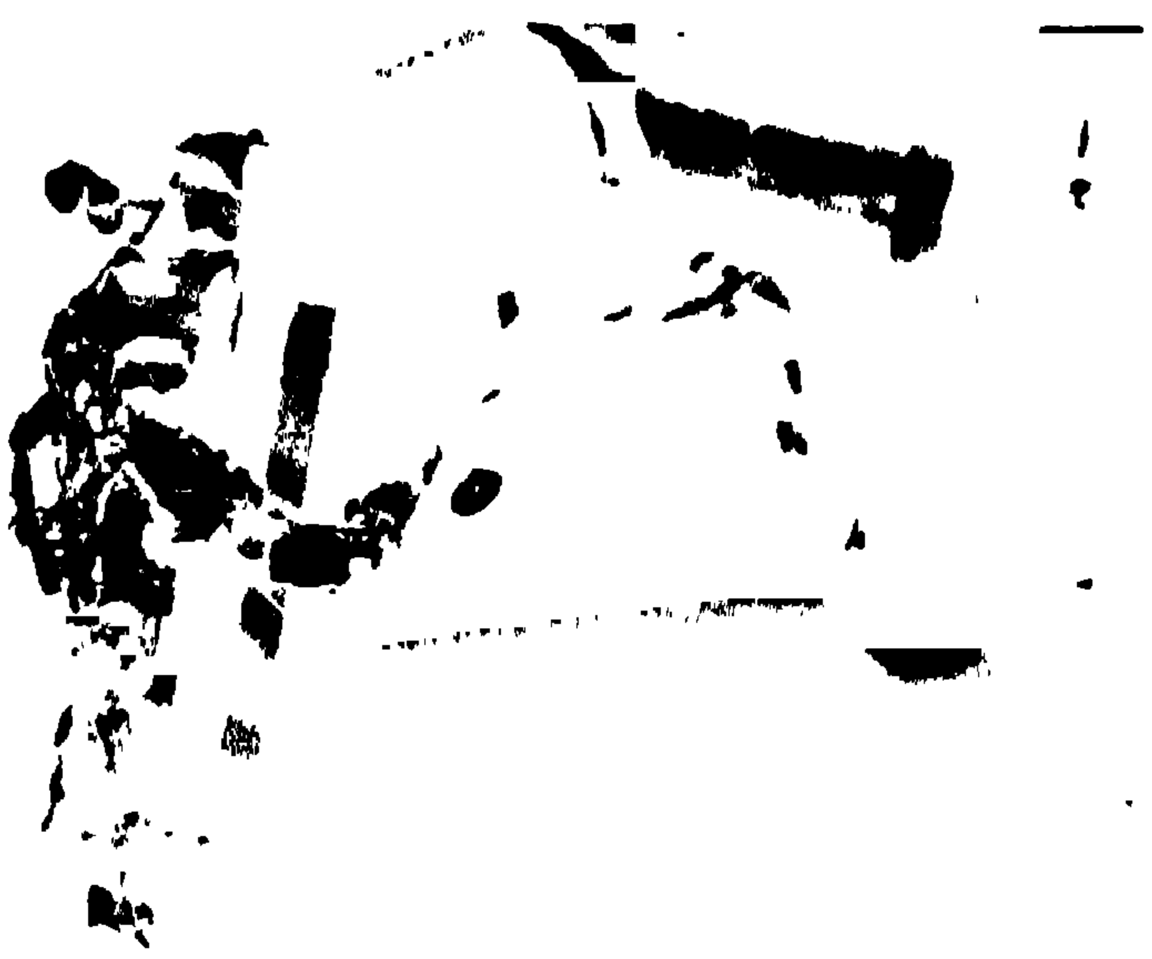


Fig.5 A block diagram of pattern classification circuit.

(1)



(2)

(3)

(4)

(5)

Object : Cylinder.
(6)

Fig. 6 A sequence of the artificial hand grasping the object for pattern classification.

		a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	a_{20}	a_{21}	a_{22}	b
Hyper-plane	I	0.5	0	0	0.5	0	-0.5	0	0	-0.5	0	0	0	0	0	0	0.5	-0.5	0	0.5	0.5	-0.5	0	0.25
	II	-0.5	-0.5	0	0	-0.5	0	0	-0.5	0	0	-0.5	0	0	0.5	0	-0.5	0	0	0	-0.5	-0.5	0	1.75
	III	-0.5	0	0.5	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	0	-0.5	-0.5	-0.5	-0.5	0.75

Table 1 A coefficient of the hyperplane equations

v_j			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pattern			2	1	2	2	2	2	1	1	1	1	1	2	2	1	1	1	1	2	2	2
Hyper-plane	s_j	I	0	1	0	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	0	1
		II	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1
		III	1	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1

Pattern 1 : Cylinder

Pattern 2 : Square pillar

Table 2 Sign table

v_j	Pattern	Hyper-plane	
		I	III
1	2	0	1
2	1	1	0
4	2	1	1
6	2	0	0

Table 3 Reduced sign table

v_j	Pattern	Hyperplane	
		I	III
1	2	*	1
2	1	1	0
6	2	0	*

* : 0 or 1

Table 4 Reduced sign table

Cylinder	Object name	C1	C2	C3	C4	C5
	Radius (mm)	70	80	90	100	110
	Correct answer (%)	0	90	100	100	50
Square pillar	Object name	S1	S2	S3	S4	S5
	Breadth (mm)	50	60	70	80	90
	Correct answer (%)	25	95	100	90	100

Table 5 The trial objects and the percentage of the correct answer for the cylinders and the square pillars.