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Abstract

An element having the mechanism of time-varying threshold has been proposed by S. Aida and denoted as an IMICTRON. Several applications of the IMICTRON 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 discussed here.

The other method using the time-varying threshold is named the Varishold method, which is an abbreviation of the variable threshold method. In this system, the threshold is applied in a discrete time, whose level is variable in each sampling time.

This paper, therefore, shows the two kinds of the pattern recognition, the one is a visual application, that is a classification by the time-varying threshold, and the other a tactile pattern recognition by the discrete variable threshold.

1. Introduction

An IMICTRON¹ network is characterized by the fact that information appears in the system, at some points, as a sequence of pulses of identical shape, generally non-equally spaced depending upon the number and period of the preceding pulse pattern, and of a positive sign; and this system is considered to be a new type of information processor. The IMICTRON has incorporated the classical axonal properties of temporal summation, time-varying threshold with a reintegration, inhibition, refractory time and all-or-none output.

The name of the IMICTRON came from its mode of coding, Time Interval Modulation Information Coding²(TIMIC or IMIC). In a TIMIC system, the interval of the output pulse is determined by the past pattern of the output sequences. Therefore, the pulse intervals in IMICTRON networks are dependent upon the input signal and a time-varying threshold level, whereas the pulse intervals in the PWM (Pulse Width Modulation) as well as PAM (Pulse Amplitude Modulation) systems may be considered signal-independent.

The authors have proposed here a neurophysiological On, Off logic, in which the information is processed by a time-varying function that is somewhat fuzzy in comparison with the conventional logical systems, and discussed here the pattern recognition for a moving object.

Recently, many results have been presented for the internal structure or information pro-

cessing of visual and auditory senses but it is impossible to realize the mechanical equipment. And tactile sense, taste sense, and smell sense are in an unknown field or a kind of fuzzy set. To increase productivity, a general purpose machine or a robot has become of major interests lately as the industrial machine to replace humans. Parts corresponding to a sensory organ which supplies external information needed to design such a machine, and parts corresponding to a cerebrum which carry out control, memory and learning are needed to process the signal from the sensory organ and parts corresponding to a hand and a leg are used to manipulate or locomote in response to an input signal.

An artificial finger, being considered as a part of general purpose machines or robots, needs the functions of sensory organ, cerebrum and hand or leg.

Therefore, the tactile sense, in the absence of visual sense such as with a blind man, is especially needed and will take over a portion of the function of the visual sense.

2. Basic Element, IMICTRON

A large number of mathematical or electrical models have appeared in the literature.³ In the IMICTRON model, the time-varying threshold dependent on the past pattern of its output pulse sequences, is the distinguishing property which makes it possible to design easily such a fuzzy logic proposed here.

2.1 Sampled-Data Model of the IMICTRON

A block diagram of the sampled-data model of the IMICTRON is presented in Fig. 1, and its main functions are described as follows.

I) Internal potential level $l(t)$ exponentially increases toward the strength of input signal $x(t)$ at time t or the empty of the input signal. Whenever the output pulse is emitted, the internal potential $l(t)$ is reset to zero.

II) Time-varying threshold level $0(t)$ is a basis for the generation of the output pulse. Whenever the internal potential is equal to or greater than the threshold level $0(t)$, the internal potential is reset to zero, and the output pulse, of duration h , is scheduled to fire. The threshold level is increased during the output pulse, then exponentially decays under C_{max} with the prescribed time constant. If the repetition rate of the output pulses increases, the threshold approaches its

minimum level with a certain period and, if no output is emitted within a certain period, the threshold level recovers to the maximum constant threshold level, Q_{max} as shown in Fig. 2, this property is a reintegration as it is called.

The specifications of the IMICTRON (the IMICTRON networks) presented here, emphasize one of the most interesting aspect of this scheme of modulation, namely, the fact that such an element transmits information in the form of pulses, when it is needed. These properties may be applicable to various fields such as the IMICTRON Modulated feedback control system¹, a learning system⁴, and a pattern recognition system.

2.2 Modified IMICTRON[^]

The modified IMICTRON is an element which is modified for the purpose of realizing On and Off responses, and a property of Adaptation* in neurophysiology. The authors have defined such models as On- or Off-IMICTRON and so on.

The modified IMICTRON is given the same property of the reintegrative action for the time-varying threshold level and its block diagram is shown in Fig. 3. The internal potential of the modified IMICTRON is not reset to zero when the output pulse is emitted. Therefore, the output pulses are continually emitted whenever the comparator's output (C in Fig. 3) is equal to or greater than zero ($C > 0$).

3. Dynamic Visual-Pattern-Recognition by IMICTRON Networks

3.1 Realization of On, Off and On-Off cell-Nets by Modified imictrons

A basic concept of On, Off and On-Off responses in a visual receptor is described in the preceding section. Here the authors set out to realize these responses by the TIMIC system and to utilize them in an information processing system. Each of the responses is realized by a modified IMICTRON.

3.1.1 On-IMICTRON: The block diagram of the On-IMICTRON is illustrated in Fig. 3. The threshold control pulse generator produces one pulse whose amplitude is m' and width d in the presence of an analog signal from a receptor.

The shape of the threshold control pulse is determined by the property of $0(t)$ and the input value $0(t)$.

3.1.2 off- imictron The Off-IMICTRON is identical to the On-IMictron in every respect but a position of the output pulses (see Fig, 5).

3.1.3 On-Off IMICTRON: On-Off IMICTRON can be realized by the threshold control pulse generator providing functions both of On and Off responses.

3.2 Network Organization

In utilizing the TIMIC system, the network configuration is basically fixed in this kind of connection. For example, the basic circuit of the movement-detection net is shown in Fig. 4. The "On" and "Off" in the circles represent the On- and Off-IMICTRON, respectively. It has been noted

* Upon application of a constant stimulus, the frequency of the nerve output pulses was fast and then soon afterward decreased.

that the natural response of the IMICTRON to a D.C. input is a non-periodic (asynchronous) sequence of pulses. This system has been constructed consisting of, (a) a receptor cone analog, providing continuous voltage output proportional to the stimulus light, (b) On- and Off-IMICTRONS which transform the signal to the pulse trains representing the "On" and "Off" responses in neurophysiology, (c) a moving spot detector IMICTRON, in the presence of pulse trains of cells #3 or #4 detects the movement in the directions as shown by the arrows. This system cannot detect the direction of movement whose speed or character (alternative moving) is such that both cells generate pulse trains at the same time. The visual resolution is determined by the factors of each IMICTRON such as their delay and threshold variables. Furthermore, this connection saves elements compared with the any of the conventional research⁵ and represents a new information processing system.

In Fig. 4, if a moving spot moves from receptors 1 to 2, the IMICTRON #3 emits several pulses by the summation of the Off- and On-IMICTRON during the prescribed time, however cell #4 does not emit enough pulses to recognize the directions or a movement. These operations are caused by the actions of spatial summation with delay to the input pulses and time-varying thresholds of the IMICTRON. After recognized the direction of a movement, when the next moving spot is moved in the opposite direction, if the threshold level of cell #3 does not recover enough toward the maximum threshold level, Q_{max} , both cells #3 and #4 emit several pulses, in this case this system cannot recognize the direction of motion. Therefore, visual resolution depends upon both the delay time for On- or Off-IMICTRON, and the recovery time of the time-varying thresholds of the IMICTRON (cells #3 and #4).

Fig. 5 illustrates the relationships between the outputs of the On- and Off IMICTRONS and the inputs of the IMICTRON cells #3 and #4, respectively in the case of a light spot moving from receptors 1 to 2.

During the simulation, each input shown in Fig. 5 is transmitted to as many as 20 Detector IMICTRONS. Each sub-input of the ordinary IMICTRONS (3&4) is a pulse train and its output is assigned by the period and number of the output pulses of the modified IMICTRON. This approach of assigning scattered sub-inputs is influenced by the school of neurophysiologists who emphasize the dendrite reception.

3.3 Results and Interpretation

This experience has indicated that the electronic system is a convenient and useful tool in the formulation and exploration of theoretical models of retina function. This type of simulation is a more simple configuration and more similar to a living system than any of the mathematical or experimental models for the visual information system, especially the delay time of On- and Off-IMICTRONS.

4. Tactile Pattern Recognition Using the VARISHOLD Method

4.1 VARISHOLD Method

The VARISHOLD Method is a shortened form of the variable threshold method. 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 the VARISHOLD Method.

It is a matter of universal knowledge that the threshold varies its levels and that a living body has the quality of being adaptable.

'The threshold is a reference level relative to external stimuli, and whose level varies due to circumstance.'

This method is to vary the threshold according to the purpose of the system as well as the input of the system.

So to speak, VARISHOLD Method intends that the authors apply a variable threshold of living body to technological system. The threshold is changed according to time, co-ordinate, and time-space. Fig. 6 illustrates some threshold variations.

4.2 Construction of Comparator

This comparator compares a given state, that is, inner-potential with the threshold.

$$m(t+r) = \text{Sgn } \Omega \quad \Omega = I_p(t) - \theta$$

$$\text{Sgn } \Omega = \begin{cases} 1 & \Omega > 0 \\ 0 & \Omega \leq 0 \end{cases}$$

where $I_p(t)$, θ , is inner-potential and threshold respectively, and r is delay time.

4.3 Tactile Pattern Recognition

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

This section discusses a possible technique, that is, the VARISHOLD Method, that is being developed for the recognition of 3-dimensional solid patterns, for example, cubic, edge, plane, etc., with view of its application to the artificial finger.

The following steps are considered as the process of artificial finger recognition with tactile sense.

- 1) Taking rough aim at the object scale or form from finger state which is gripping the object.
- 2) Taking the state of the object surface by tactile sense.
- 3) Taking the state of the other surface by changing the grip state of the finger.
- 4) Recognizing the object from the information of step 1 - step 3.

Main discussion is the surface state of step 2, as shown in Fig. 7.

4.4 Technological Model of Tactile Receptor

As shown in Fig. 8, a simple model of tactile receptor is constructed from its physiological one. It is well known that sensory nerve and its ending which serve tactile sense exist in skin. The model eliminates temperature, pain and touch sensation of tactile sense and put a pressure-electric transformation element or pressure sensor

corresponding to pressure sense.

Moreover, the surroundings of its elements are filled by approximate elastic material. When any object comes in contact with the surface of the model, a strain resulting in elastic deformation of material transmits to the pressure-elastic transformation element, and is converted to electrical signals.

4.5 Construction of Receptor

It is known that the physiological receptor corresponding to pressure sense is the Pacinian corpuscle. Pacinian corpuscles emit impulses according to corpuscle deformation which results from the strain of skin tissue that is caused by the pressure of an object on the skin. There are larger ones (with a length of 500 μ and diameter of 500 μ) in comparison with the other cells. The sensory nerve ending in its corpuscle is surrounded by a lamellated fluid-filled capsule which is dependent on the viscous element.

Therefore, the receptor unit corresponds to the pacinian corpuscle described above and its unit input constructed as shown in Fig. 9 can be considered as the skin surface or surface of a pacinian corpuscle.

It is suitable for our purpose to treat inner-potential I_p , as the transfer function "G" is apparently complicated.

The globular surface contacting on the surface, Fig. 10 shows the pressure distribution occurring on the receptive field corresponding to a sensory nerve cell group. Its distribution is 3-dimensional.

The response of pressure distribution can be taken by the information for each threshold.

5. Recognition of the Pressure Distribution

From the result of the preceding section, it is made to recognize the pressure distribution due to the object by using the VARISHOLD Method.

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

It is clearly shown that,

$$V \subseteq R \subseteq E$$

A set $V(x,y,z)$ is supposed as a convex from the object properties. Moreover, the threshold distribution θ is considered as a plane $P(\theta)$.

Consider the intersection X_i between $V(x,y,z)$ and $P(\theta)$:

$$X_i = V(x,y,z) \cap P(\theta)$$

for

$$i = 1, 2, 3, \dots, n$$

where θ is taken by the value which X_i is not an empty set.

Namely, $P(\theta_{i=1})$ is taken the supporting hyperplane to $V(x,y,z)$.

Suppose

$$P(\theta_i) = \theta_i, \Delta\theta_i = \theta_i - \theta_{i+1}$$

$V(x,y,z)$ may be written approximately,

$$V \simeq V_1 \otimes V_2 \otimes \dots \otimes V_n$$

$$V_i = X_i \otimes \Delta \theta_i$$

where \otimes, \otimes is a direct sum, a direct product, respectively.

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

Pattern V is approximately described by the pattern X_{Bi} recognized in close succession. For example, the 2-dimensional pattern X_{Bi} corresponding to threshold θ is shown in Fig. 11.

Intersection \tilde{X} between standard plane \tilde{P} and $V(x,y,z)$ is shown by the following:

$$\tilde{X} = V \cap \tilde{P}$$

where $\tilde{P} = P(\theta; \delta)$, δ is a small value.

\tilde{P} and $P(\theta_i)$ are planes and parallel to each other.

Defining 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 $P(\theta_i)$, and let u'_i be a point such that

$$u'_i = \tilde{l}'(u_i) \cap \tilde{P}$$

then, a parallel projection can be defined (see Fig. 10) and denoted

$$\prod_{\tilde{l}, \tilde{P}} (u_i) = u'_i$$

By the parallel projection of \tilde{P} in the direction \tilde{l} over the elements of the set X_i , X'_i is denoted by

$$\prod_{\tilde{l}, \tilde{P}} (X_i) = X'_i$$

for $i=1,2,\dots,n$

Subscript i corresponds to the threshold θ_i and in the case of the subscript $i=1$, the plane $P(\theta_{i=1})$ is decided on a supporting hyperplane.

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

1) Pillared form

$$X'_1 = X'_2 = \dots = X'_n = X$$

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

$$P = X'_1 \subset X'_2 \subset \dots \subset X'_n \subset \tilde{X}$$

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

$$s = X'_1 \subset X'_2 \subset \dots \subset X'_n \subset \tilde{X}$$

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

4) Frustum

$$\omega = X'_1 \subset X'_2 \subset \dots \subset X'_n \subset \tilde{X}$$

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

$$R = X'_1 = X'_2 = \dots = X'_n = \tilde{X}$$

where P, s, ω is a point, segment and a small closed plane, respectively.

6. Digital Simulation

Some examples of the pattern have been simulated on a digital computer. Simplified flow diagram of simulation is given in Fig. 12.

The size of the receptive field used for the simulation is a 40 x 40 lattice structure.

A test pressure pattern is the convex set and is generated by solving a pattern equation. The amplitude of the pressure applied on the lattice point is normalized in 10 steps.

The recognition is carried out by the described method which generates the periphery pattern corresponding to each threshold.

The 3-dimensional object, for example, spherical form, has been recognized by the relationship between the threshold and its corresponding pattern, that is, circular.

7. Conclusion

This paper has described the application of the IMICTRON, that is a new type of information processing model. In the system described, the time-varying threshold element, IMICTRON proposed by the authors, simulates the neurophysiological phenomena in the single element and reduced to about 50 per cent the elements needed for designing a dynamic visual-pattern-recognition network.⁵

This paper also discusses the tactile pattern recognition, but this method is not completed and is difficult to apply directly for a machine. However, this pattern recognition is able to carry out easily a part of solid body in comparison with visual sense, if we can realize such a receptor for the machines.

A large scale solid object may be observed by a combination of the described method and the

movement of finger tips. Moreover, it may be recognized by a continuous movement of the finger tips. And the VARISHOLD Method will be applied to the various engineering fields.

References

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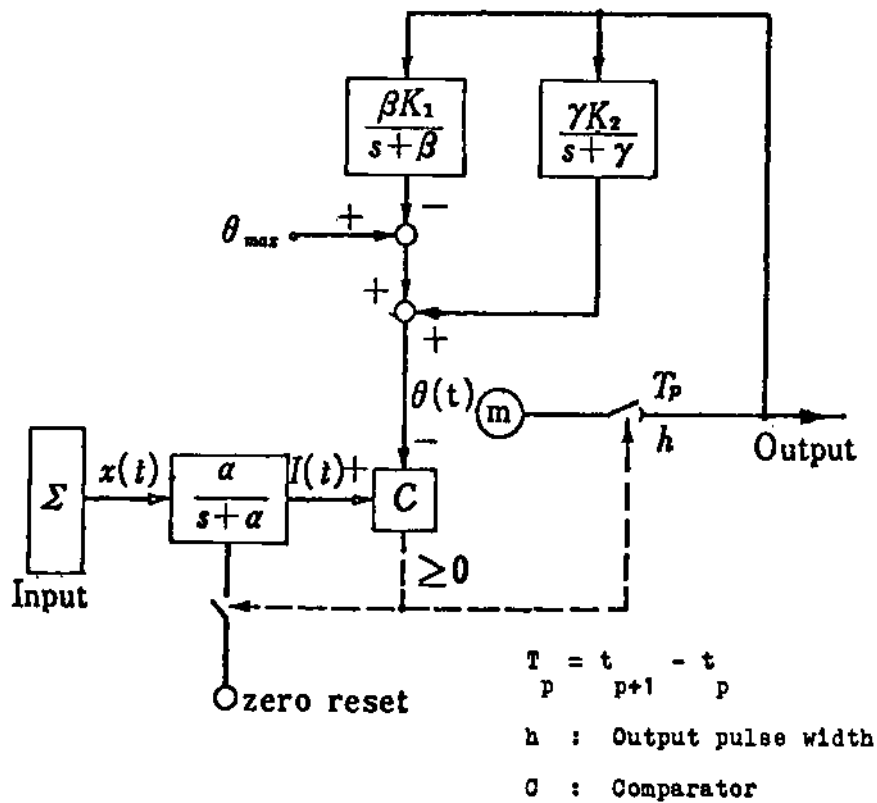


Fig. 1 The sampled-data model for the IMICTRON

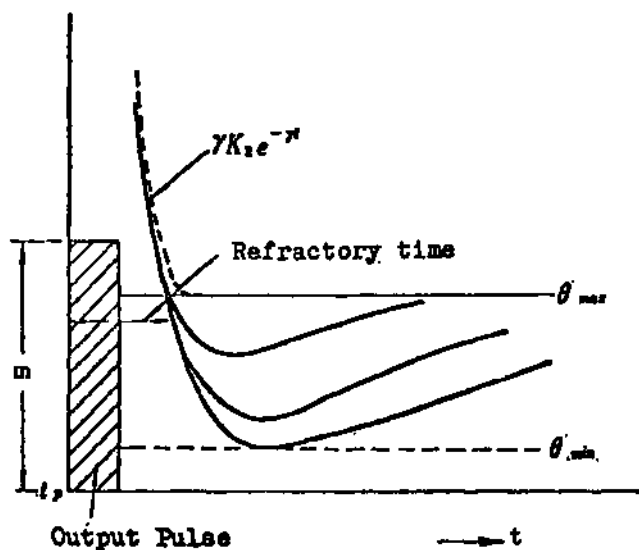


Fig. 2 The relationship between the period of the output pulse and the time-varying threshold with a reintegration.

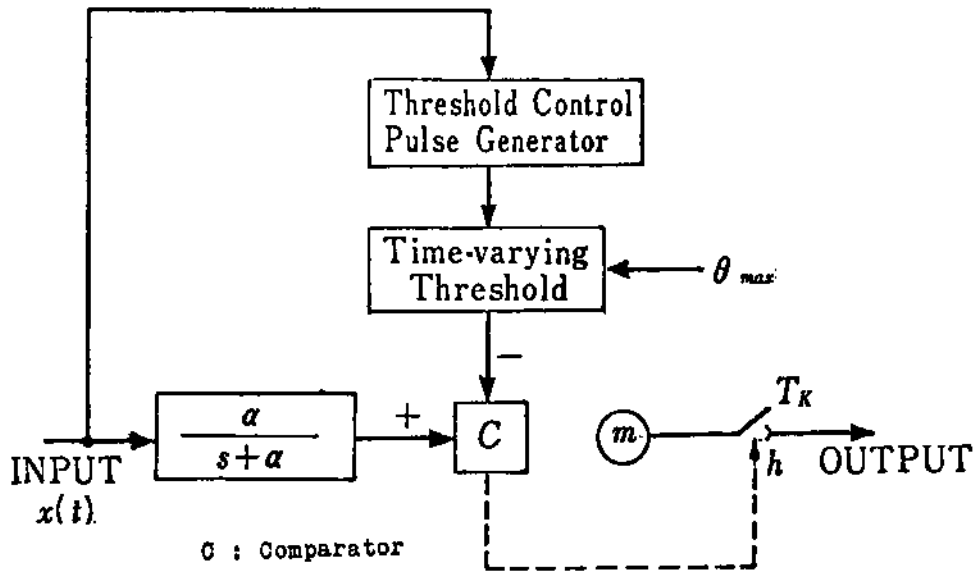


Fig. 3 The block diagram of the modified IMICTRON.

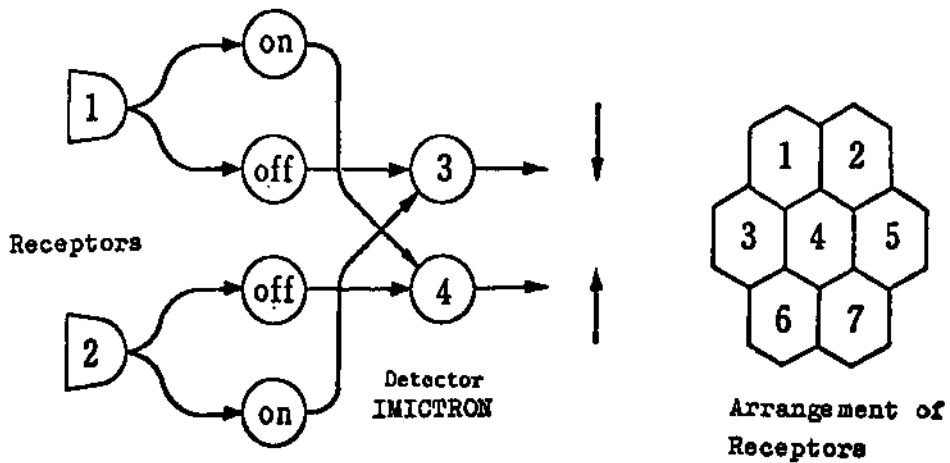


Fig. 4 The basic connection of a two-receptor movement detection net by the IMICTRON. Cells #3 and #4 detect the movement in the directions as shown by the arrows.

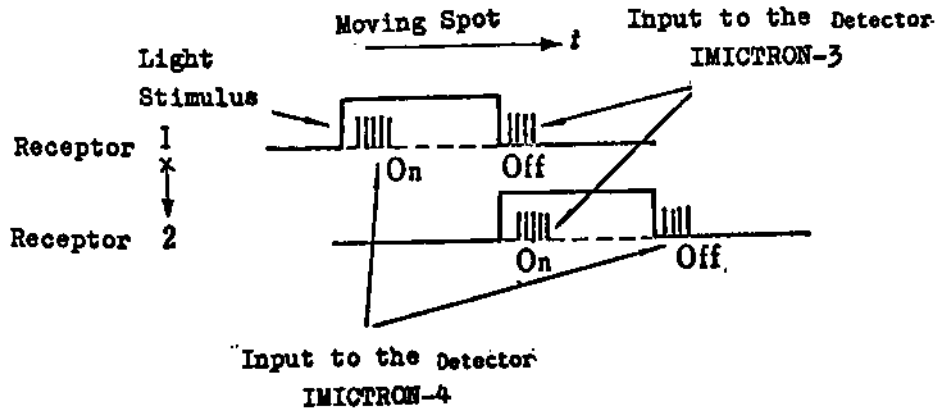


Fig. 5 The waveforms of the networks as shown in Fig. 4.

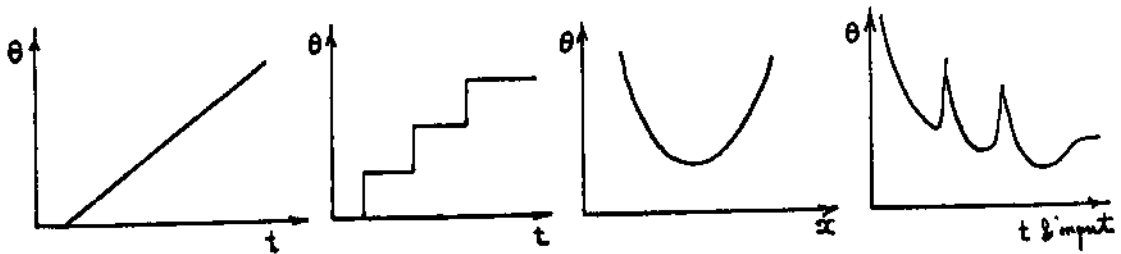


Fig. 6 The examples of threshold distribution.



Fig. 7 The examples of objects.

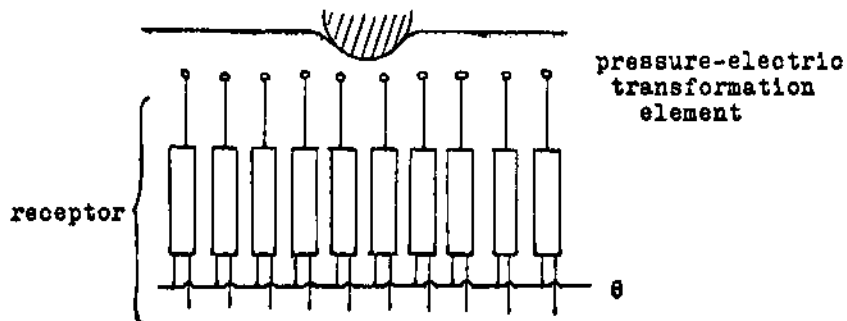
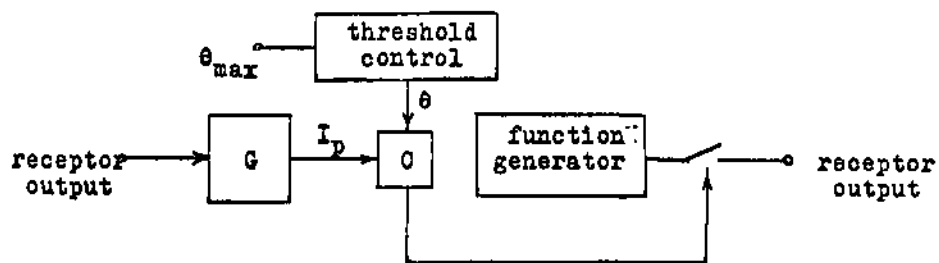


Fig. 8 The schematic diagram of a tactile model.



I_p : Inner potential G : Transfer function

O : Comparator

Fig. 9 The schematic diagram of a tactile receptor.

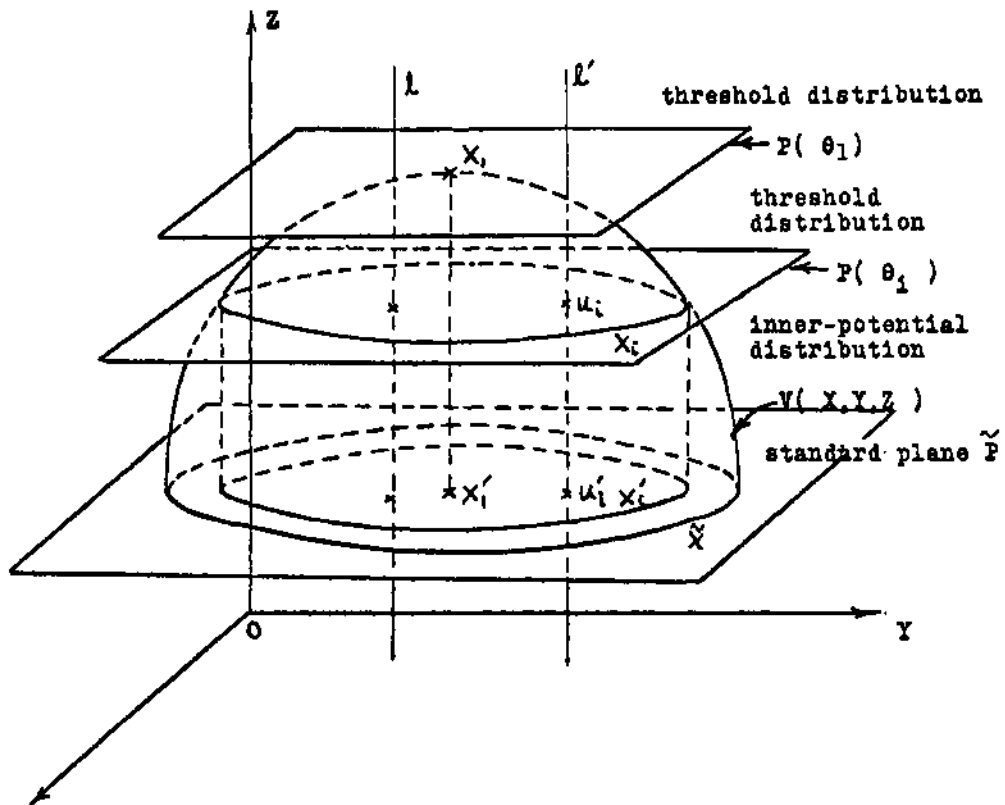


Fig. 10 The pattern classification by using parallel projection.

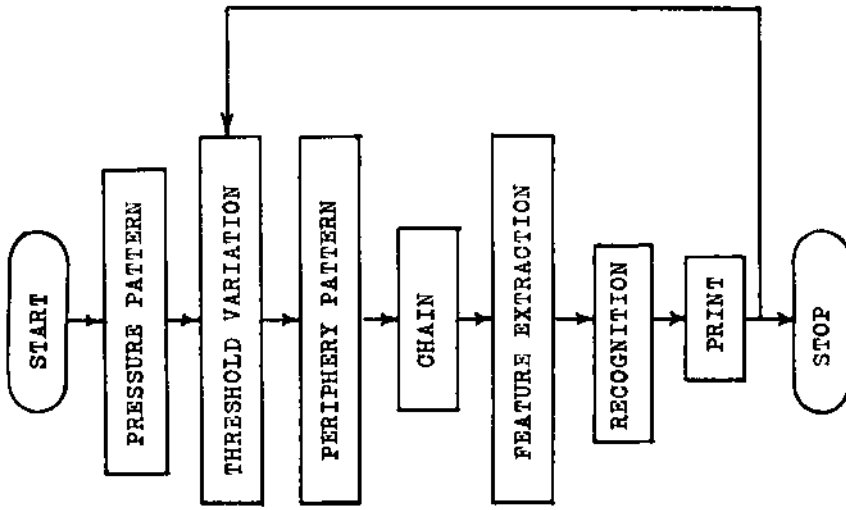


Fig. 12 Flow diagram.

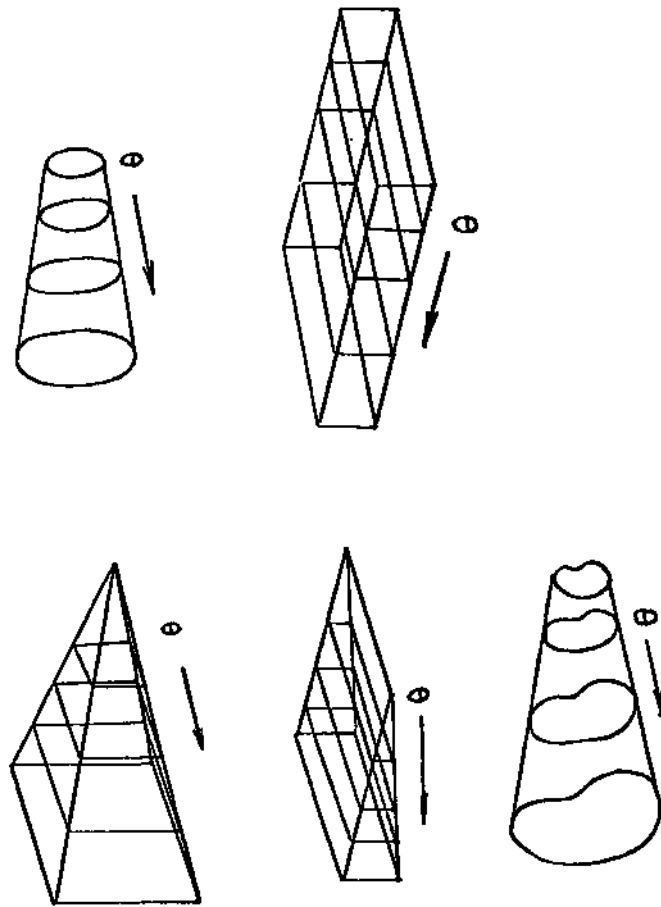


Fig. 11 The pattern variation for each threshold level.