A DYNAMIC PATTERN RECOGNITION METHOD USING THE PREVIEW CONTROLLED SACCADIC MOVEMENT OF THE DETECTOR

Recognition independent of position, rotation, size, or slight deformation of the object.

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Abstruct

The purpose of this paper is to suggest the use of biological movements of detectors for pattern recognition. The authors demonstrate a unique method for recognizing patterns composed of straight and curved lines such as characters or edge patterns, independent of position, rotation, size, or slight deformation. The principle of the method is, different from conventional scanning techniques, based on preview controlled curve tracking movement similar to the saccadic motion of the eye. The recognition depends on the time sequence of straight line, curve, angle, intersection, etc. Discrimination between a straight and a curved line, larger or small curvature, and obtuse or acute angle is based on the relative difficulty in tracking the line. For small patterns which lie completely within the field of the detector, a well-known multi-layered recognition device is superior. For larger patterns, however, which lie partially outside the field, the method proposed here is superior.

The authors think that their method could be useful for the eyes of robots when combined with the kind of multi-layered pattern recognition devices described by Fukushima*).

Notation

The following notation is used in the paper:

E : edge point
I : pulse signal generated from the inside preview photo-cell P_{pi}
Kj : constant
K2 : constant
0 : pulse signal generated from the outside preview photo-cell P_{po}
P_{pi} inside preview photo-cell
P_{po} outside preview photo-cell
P_s photo-cell for servo-tracking
R radius of curvature of segment of the pattern
S distance from an end point of a pattern to the detector
T tracking time, or T shaped part of a pattern
V tracking speed of optical detector, or angle
W wait
/ straight line segment of a pattern
_ straight line segment of a pattern
) arc or curved line segment of a pattern
⌒ arc or curved line segment of a pattern
\+ intersection
∠ angle
m.p i. : measurement of pulses intervals

Introduction

One of the important problems in pattern recognition is the development of techniques to overcome the difficulties of translation and rotation.

It is a fact, proved experimentally, that we cannot see the shape of an object if there is no relative motion between the eyeball and the object. Moreover, it is a well known fact also that the frogs do not respond to stationary objects. These facts suggest that movement of the optical detector is a necessary condition for the level of pattern recognition that is found in many animals.

So the authors would like to propose here a novel and simple method which employs mechanical movement of the optical detector. The movement is like the saccadic motion of the human eye. By this method, it is possible to recognize patterns composed of straight and curved lines such as characters and edge patterns independently of their position, rotation, size, or slight deformation.

Although the development of the equipment is still incomplete and the tracking speed of the detector is not yet adequate, the authors will outline this method and would appreciate your candid criticism.

Tracking time independent of sizg and deformation

It is assumed that the line tracking speed V of a optical detector is a decreasing function of the relative difficulty in following the line. For instance, the curvature is a measure of the difficulty in line tracking. This can be expressed mathematically as.

$$V = \frac{K_1 R}{1 + K_2 R} \qquad (1)$$

where

V ■ tracking speed of the optical detector
R « radius of curvature of segment of the pattern
K_1» K_2 * constans

The relation between V and R is shown in Fig.I. From this relation the following important characteristics are obtained.

1) The tracking speed decreases with the radius of curvature. This means that the tracking times are nearly the same whether the arc is small or large as long as it has the same center of curvature and an equal subtended angle.

2) For large R, V is approximately constant. For straight lines, the tracking times are negligibly snail. Therefore, it can be seen that the length of a straight line segment has no effect on the total tracking time for a pattern.
3) The optical detector stops momentarily at a corner, that is, lim V ■ 0.

From conditions 1) and 2) the following performance characteristics are obtained.

The tracking time of the detector scarcely differs for patterns of various sizes.

If we plot, for instance, the relation of S to R for the numerals 2 and A (where S is the distance from an end point of the pattern to the detector), we get Fig.2 (a) and (b). We can see that curve (a) and curve (b) are not the same. Then if we transform this S-R relation using Equation (1), we get S-V relations such as Fig.2 (a^1) and (b^t). Again if we transform the S-V to T-V relations using

$$dT \ll \frac{dS}{V} \qquad (2)$$

where T=tracking time
we obtain Fig.2(a") and (b").

Now, we can see that curve (a^n) is almost the same as curve (b":). Table I gives examples of the T-V relations for the numerals 0 to 9.

Thus, we have found a pattern recognition method independent of size and slight deformation.

Since the method is based on a detector servo-tracking system, it has no fixed coordinates about the object. Therefore, it is also independent of rotation and translation of the pattern.

To mechanize this saccadic movement of the detector, a preview method will now be proposed.

Preview algorithm

Table II shows sequences composed of straight lines, curved lines, intersections, and "T's" for the numerals 0 to 9. Consider the optical detector, shown in Fig.3, which has two photo-cells Ppi and PpQ for the preview action and one or more photo-cells P_s for the conventional servo-tracking. The inside preview photo-cell P_{pi} and the outside preview photo-cell Ppo rotate at a suitable speed. As the detector tracks a pattern, Ppi and Po generate a cyclic pulse sequence such as shown in Fig.4. The pulse generated from P_pi is denoted as I, and pulse from Ppo, as 0. Table III shows some typical examples of the 1-0 pulse sequence. For the patterns of the numerals 0 to 9 which we are taking as examples in this paper, the i-0 sequences shown by the tree algorithm in Fig.5 are sufficient to distinguish between the straight line, curve, intersection, "T", and end point. This discrimination is performed easily by an electronic circuit or by a computer.

The output signals from the discrimination circuit are fed to the detector-servo-system to control its tracking speed according to whether the pattern is a straight line, curve, intersection, etc. Thus, the optical detector tracks at a velocity appropriate to the radius of curvature of the segments of the pattern. This is analogous to driving a car at high speed on a straight road, at medium speed on a curved one, and at slow speed or with a momentary stop at a corner.

Fig.6 is a block diagram for the preview controlled tracking servo-system.

Dynamic and coordinate-free pattern recognition

Pattern recognition, the ultimate goal, is done by descriminating between sequences of straight lines, arcs, intersections, and ''T's" as shown in Table II. This is performed also by an electronic logic circuit or by a computer.

The method proposed is based on a detector-servo, pattern-tracking system. Different from conventional scanning methods, this dynamic system needs no fixed coordinates for recognition, and so it is independent of rotation and translation of patterns. Moreover the recognition method is based upon the sequential combination of unit patterns. Furthermore, the use of conditions 1) and 2) mentioned above very effectively equalizes the tracking time, and removes the restrictions on pattern size and slight deformation.

Conclusions

The saccadic movement of the detector has a number of advantages. Besides being quite simple, it is independent of the location, rotation, size, or slight deformation of the pattern. Here we described a preview method using two photocells. There are other methods available for the preview action. For example, linear or quadratic prediction methods having learning abilities are possible. The errors of the tracking servo-system can be used as a measure of the relative difficulty of the tracking. Though these detailed subjects are interesting and important, the principal point of their paper is to introduce the saccadic motion tracking method of pattern recognition which overcomes the limitations of fixed coordinates.

The authors believe that the method presented here could be effective for eyes of robots if combined with multi-layered devices having variable thresholds2).

References

1) K. Fukushima, "Feature Extraction from Visual Pattern by Multi-Layered Network of Analog Threshold Elements*1, IEEE Trans. IT, to be published.

2) S. Aida, "Theory and Applications of A Living Neuron", Report of The Institute of Industrial Science The University of Tokyo, Vol.15, No.5, 1967.

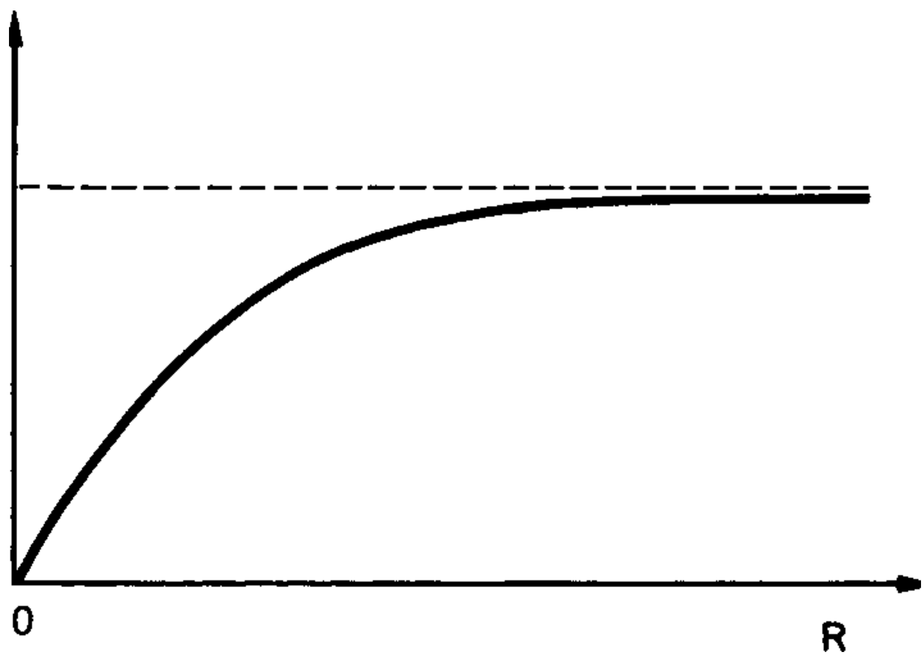


Fig.l An example of tracking speed V vs. radius of curvature R

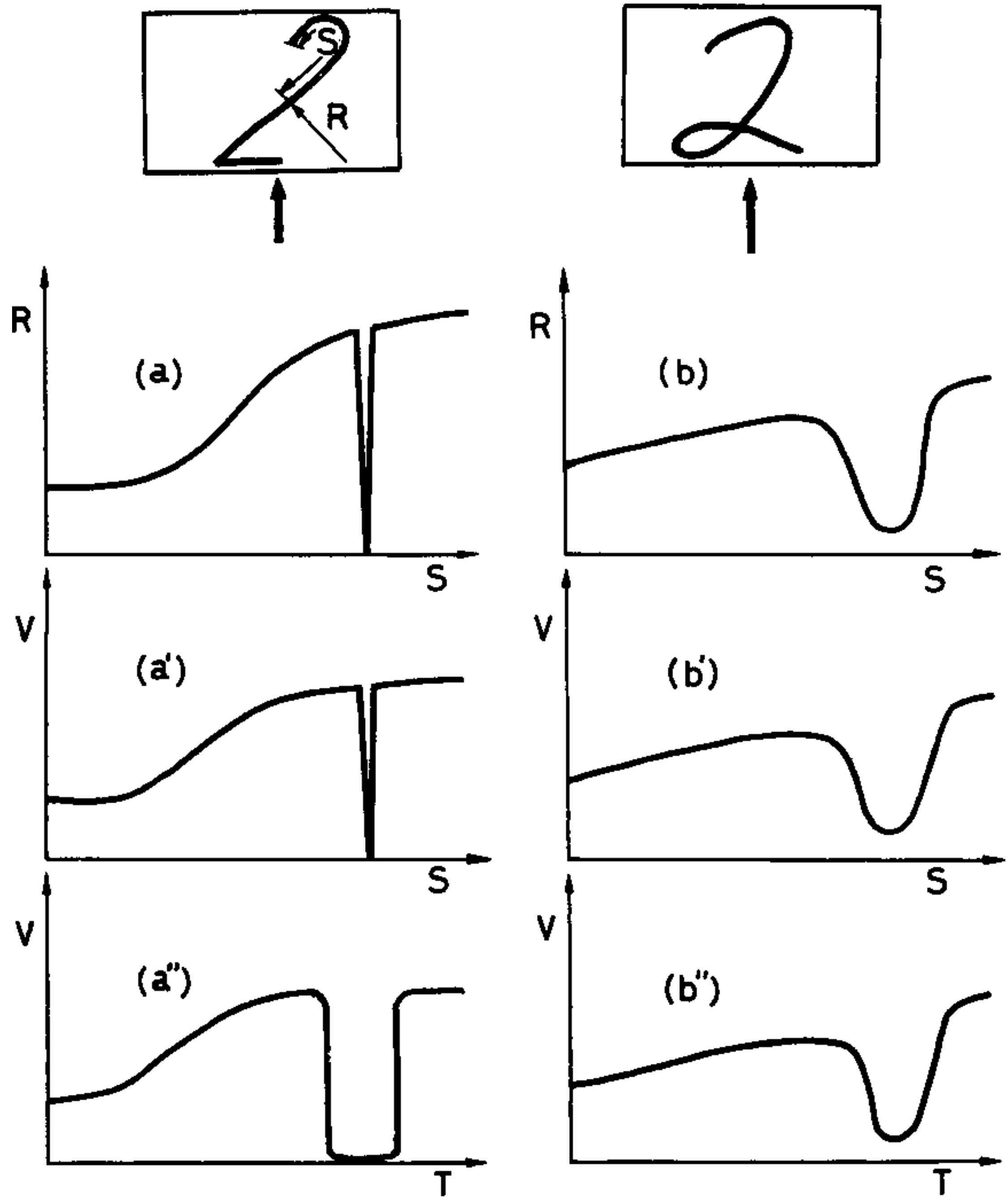


Fig.2 The T-V relations are powerful to normalize pattern deformations.

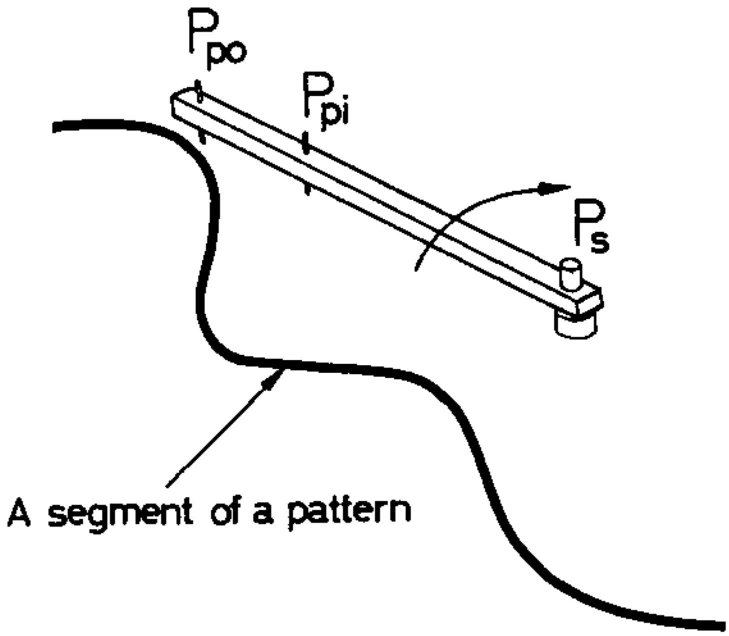


Fig.3 Optical detector

P_{po} : Outside preview photocell
P_{pi} : Inside preview photocell
P_s : Photocell for servo-tracking

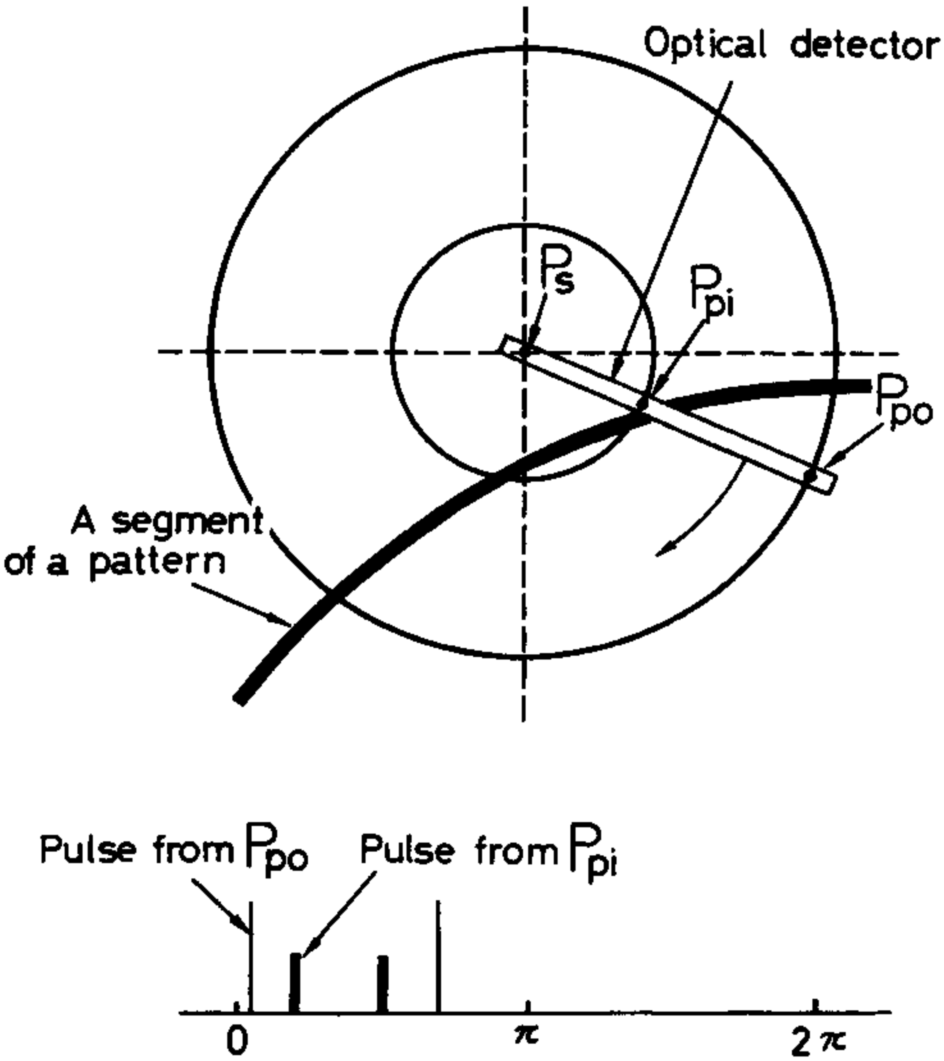


Fig.4 The inside preview photocell P_{pi} and the outside preview photocell P_{po} generate cyclic pulse sequence

: Pulse from the inside preview photocell P_{pi}.

: Pulse from the outside preview photocell P_{po}.

/: Straight line
): Arc
E: Edge point
+: Cross
T: "T"
V: Angle
W: Wait
m.p.i. : Measurement of pulses intervals

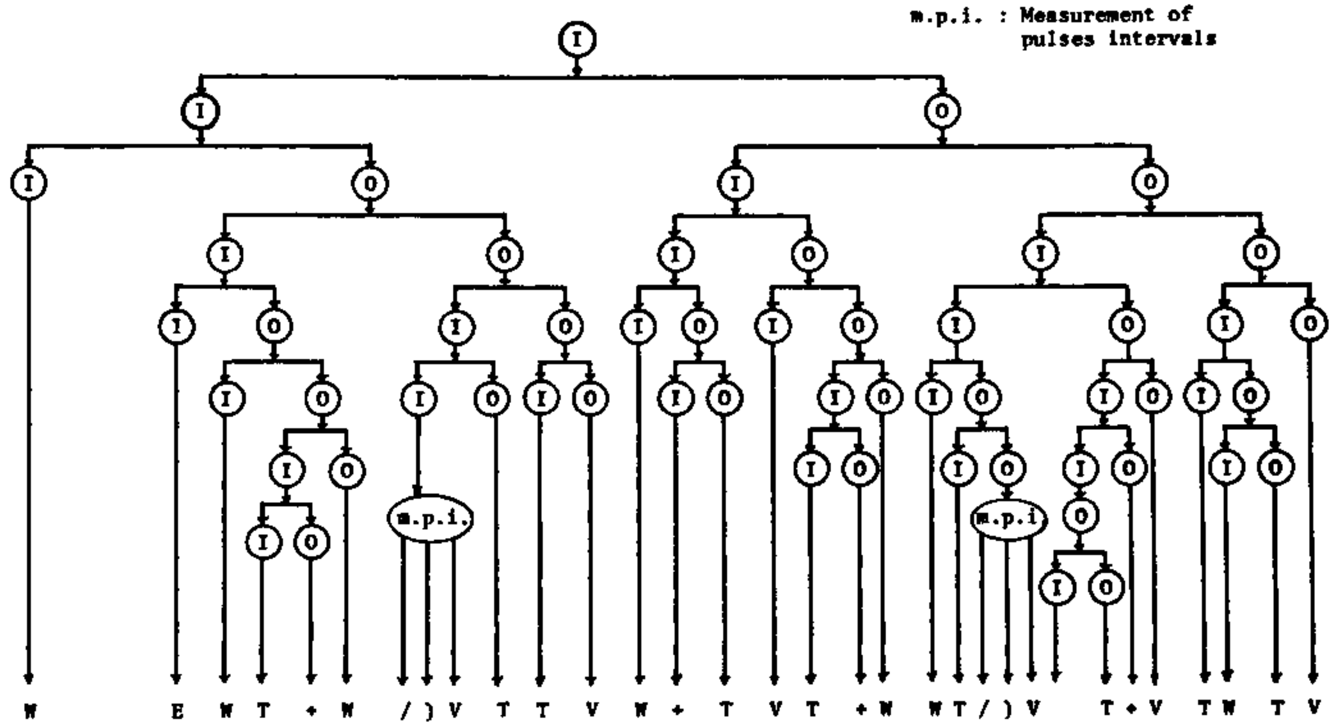


Fig.5 An example of tree algorithms for the I-O sequence (for the numerals 0 to 9)

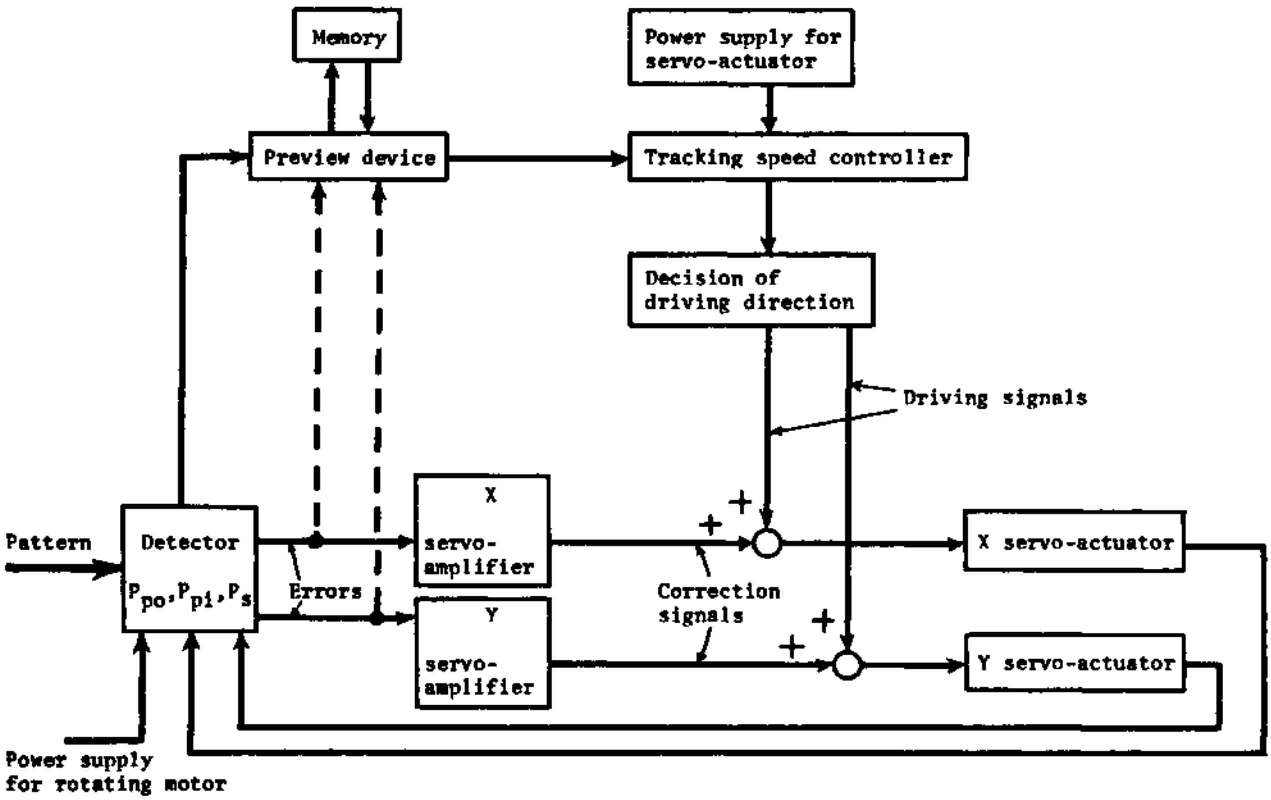


Fig.6 Block diagram of the preview controlled tracking servo-system

Table I   T-V relations for handwritten numerals 0 to 9

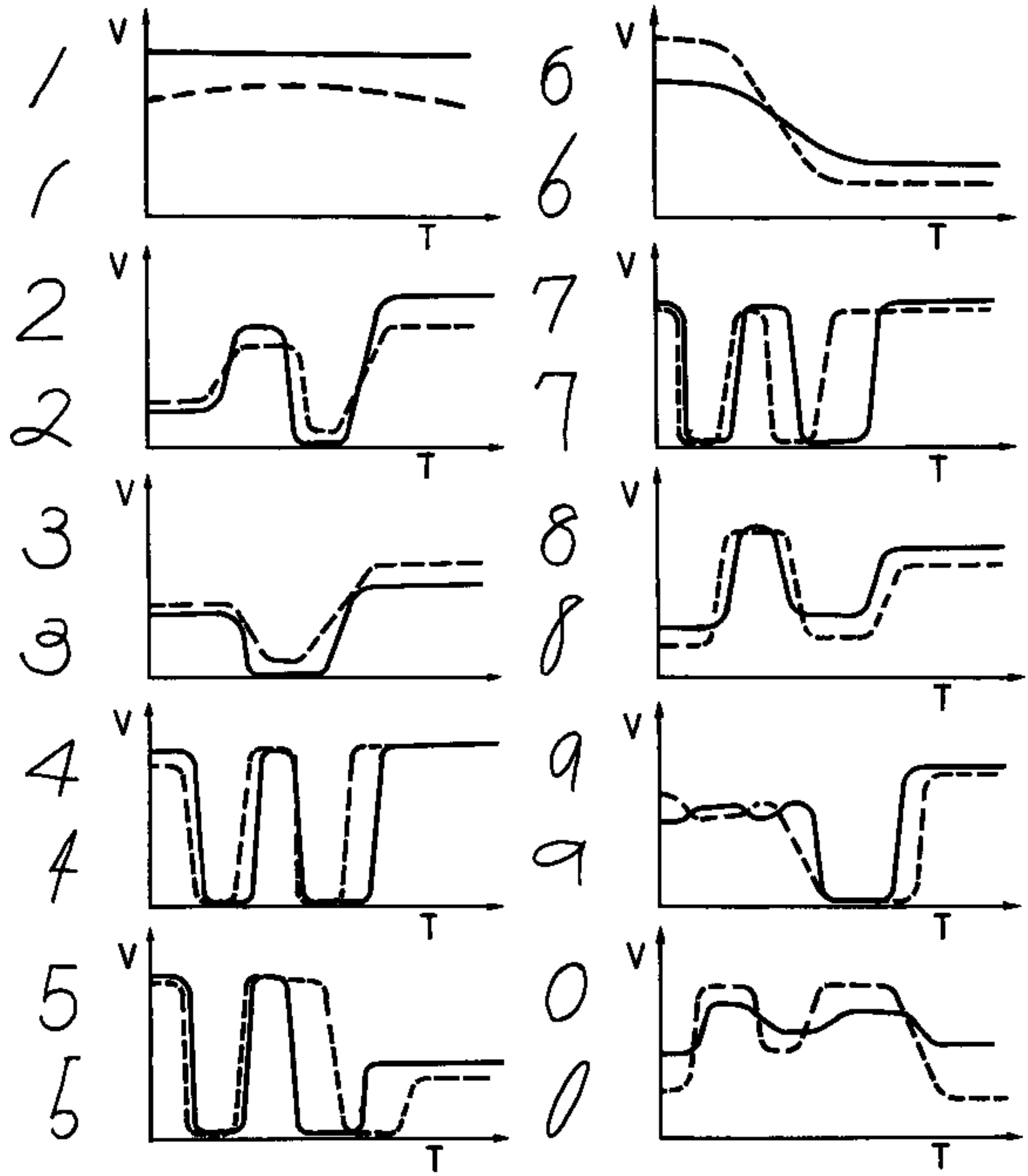
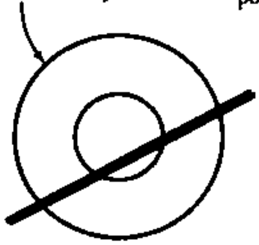
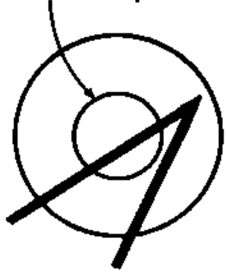
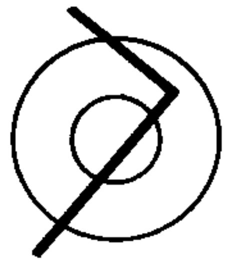
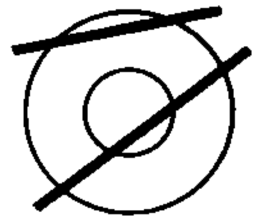
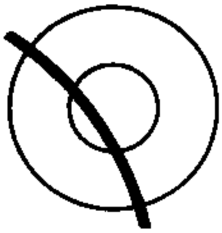
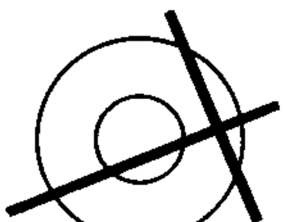
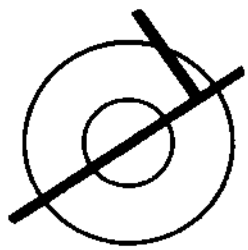
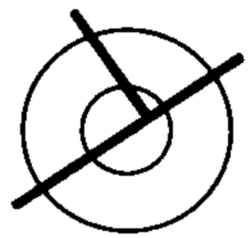


Table II   Sequences for the recognition of numerals 0 to 9.

Patterns	Tracking Sequences					
0	⌒					
1	—					
2	⌒	∠				
3	⌒	∠	⌒			
4	—	+	∠	∠	+	—
5	∠	∠	⌒			
6	⌒	⊤	⌒	⊤		
7	∠	∠				
8	⌒	+	⌒	+	⌒	
9	⌒	⊤	∠			

Table III Some typical examples of I-O pulse sequences. (Simultaneous I-O pulses are regarded as one pulse.)

			
a straight line	an angle	an angle	pattern for predicting an acute angle
I-I-0-0	I-0	I-I-0-0	I-I-0-0-0-0
			
a curve	a cross	a "T"	a "T"
I-I-0-0	I-0-I-0-0-0	0	I-0-0-0