XV. COGNITIVE INFORMATION PROCESSING

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A. THE DISTINCTIVE FEATURES OF THE LETTERS O AND D

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Joint Services Electronics Program (Contract DAAB07-75-C-1346)
National Science Foundation (Grant ENG74-24344)

Robert J. Shillman, Gregory J. Naus

An approach to automatic character recognition based on human perception has been reported elsewhere.[1-3] In this approach, letters are described in terms of an abstract set of functional attributes, each of which can be related to a type of ambiguity between two letters. The relations between the physical attributes derived from the physical image and the functional attributes that specify the letter's identity are called physical-to-functional rules (PFRs). The PFR for the attribute LEG which distinguishes Y from V, F from C, P from D, H from U and A from O has been determined.[4] Our current work deals with the attribute SYMMETRY which has been hypothesized to be the attribute that distinguishes the letter O from the letter D.

Two experiments were performed: in the first experiment characters from two different O-D trajectories were utilized in an attempt to describe the interletter boundary; the second experiment was an investigation to find out whether the labeling of a

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JSEP character as an O or a D depends upon the categorization of the left side of the character as functionally curved or functionally straight.

1. Experiment 1

The purpose of this experiment was to investigate the O-D boundary in order to determine the physical-to-functional rule (PFR) for symmetry which has been postulated[1] as the feature that distinguishes O from D. The stimuli in this experiment were 1-inch characters from two O-D trajectories; copies of a few of the stimuli and details of their construction are shown in Fig. XV-1. All stimuli were drawn 2.5 times final size with a Mars No. 1 drafting pen and were photographically reduced to a character height of

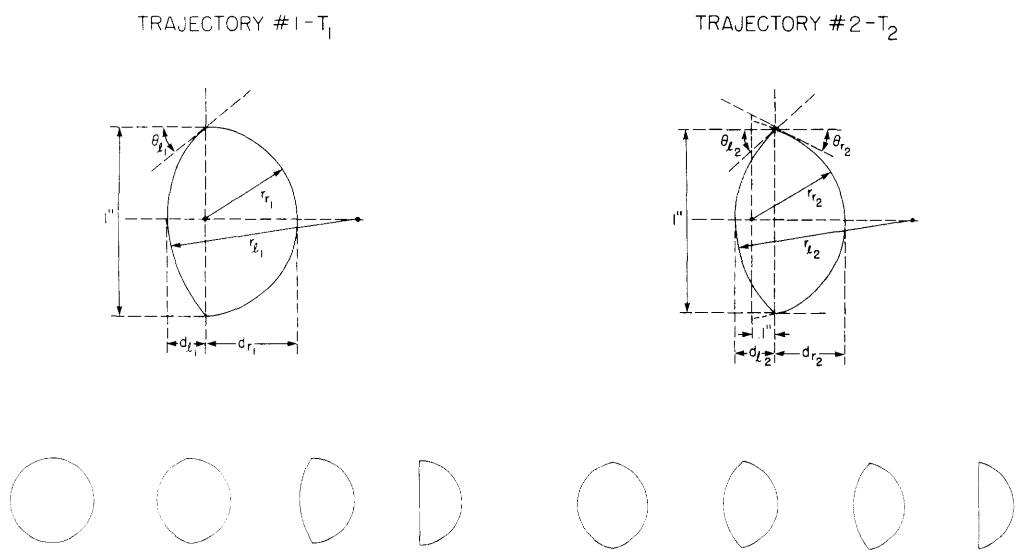

Fig. XV-1. Various stimuli from two O-D trajectories and details of their construction.

1 inch. For each trajectory the actual stimuli used in the experiment were black and white photographs 2.5 inches square with a 1-inch high character centered on each.

Along the first trajectory, T_1, the right side of each character was always a semicircle of .5 inch radius, and the left side was always an arc of a circle whose radius of curvature, r_{ℓ_1}, was the independent variable. Table XV-1 lists the values of r_{ℓ_1} for the 28 stimuli of T_1; the values range from .5 inch (for a circle) to ∞ (for a semicircle). As in T_1, the right side of each character along T_2 was also held constant. In T_2 the right side was an arc of less than 180°, as shown in Fig. XV-1; the radius of curvature of the left side, r_{ℓ_2}, was the independent variable (the specific values used are listed in

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Table XV-1. Values of r_ℓ for T_1 and T_2 used in Experiment 1.

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Trajectory 1		Trajectory 2	
Stimulus No.	r_{ℓ_1}	Stimulus No.	r_{ℓ_1}
1-1	0.500	2-1	0.500
1-2	0.506	2-2	0.522
1-3	0.525	2-3	0.658
1-4	0.554	2-4	0.688
1-5	0.594	2-5	0.721
1-6	0.616	2-6	0.754
1-7	0.640	2-7	0.790
1-8	0.666	2-8	0.826
1-9	0.693	2-9	0.864
1-10	0.721	2-10	0.941
1-11	0.751	2-11	1.021
1-12	0.781	2-12	1.106
1-13	0.812	2-13	1.318
1-14	0.844	2-14	3.426
1-15	0.876	2-15	∞
1-16	0.910		
1-17	0.943		
1-18	0.978		
1-19	1.012		
1-20	1.047		
1-21	1.082		
1-22	1.118		
1-23	1.154		
1-24	1.226		
1-25	1.300		
1-26	1.676		
1-27	2.844		
1-28	∞		

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JSEP pieces of white cardboard in ascending order of r_ℓ.

Twenty members of the M.I.T. community served as subjects, for all of whom English was their native language. Each subject was seated at a table under normal room light and was instructed to choose the character in each trajectory that was as much like an O as a D. Each subject was tested individually, and the order of presentation of the two trajectories was counterbalanced.

The PFR for SYMMETRY might have the following form:

$$\left[\text{Functional SYMMETRY:} \quad f \quad \begin{matrix}\text{present}\\ > \\ < \\ \text{not}\\ \text{present}\end{matrix} \quad \alpha\right]$$

The goal, then, is to find a function, f, of some physical variables and a threshold, α, which can be used together to predict letter labeling along both O-D trajectories. (Along any single trajectory there are many functions and thresholds that will work; the general problem is to find a rule that holds along a number of different trajectories.) A variety of hypotheses were generated concerning the specific form of the function f: possible arguments for f are θ_ℓ, θ_r, d_ℓ, d_r, r_ℓ, and r_r. Analysis of the data indicates that the subjects' labeling criterion along both O-D trajectories can be described by using r_ℓ alone. Along T_1, the mean value of r_ℓ for the ambiguous stimuli is .724 ($\sigma_{r_\ell} = .065$) and along T_2 the mean value is .732 ($\sigma_{r_r} = .074$); these values are not statistically different ($t_{19} = 1.36$). Other variables were tested, for example, $\theta_\ell - \theta_r$, d_ℓ/d_r, d_ℓ, θ_ℓ, but across T_1 and T_2 all of these "simple" combinations are not consistent.

The data indicate that for $r_\ell < .728$ inch the characters are more likely to be called O than D; however, the character  has $r_\ell < .728$ inch and yet it is more likely to be called D than O, and the character  has straight sides ($r = \infty$) yet it is an O. Clearly then, the letter label cannot depend just on the left side of the character. It is more likely that each half of the character is categorized as functionally curved or functionally straight (based on $r \lesseqgtr .728$) and then a comparison is made between the two categorizations. If both sides are categorized alike, then the character is an O; otherwise it is a D. This hypothesis is consistent with the data that were obtained; along both T_1 and T_2, each character had $r_r < .728$ and hence the right sides were all functionally curved, and so letter label could be predicted by looking at r_ℓ alone. Experiment 2 was undertaken to investigate this hypothesis of categorical perception of curvature.

2. Experiment 2

The purpose of this experiment was to investigate the mapping from physical curvature to functional curvature using geometrical shapes, and then to determine whether JSEP the obtained mapping is consistent with the results of Experiment 1 in which letterlike shapes were used.

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The left portion of each stimulus from T_1 in Experiment 1 was reproduced in the center of a 2.5×2.5 inch black and white photograph. The 28 stimuli thus were composed of arcs, concave to the right, ranging from a semicircle ($r = .5$ inch) to a straight line ($r = \infty$); the stimuli were mounted on white cardboard in ascending order of r.

Twenty members of the M. I. T. community served as subjects, for all of whom English was their native language, and none of them had participated in Experiment 1. (Twenty-two subjects were tested. Two of these subjects, however, chose the first perceptually curved stimulus. This performance was significantly different from the performance of all other subjects and hence data from these subjects were not used in the analysis.) Each subject was told that the experiment concerned shape recognition and that his task was to choose the shape that was as much like the straight line as it was like the half circle. The radius of curvature for the ambiguous character chosen by each subject was recorded; the mean value across subjects was $r = .716$ inch ($\sigma_r = .128$ inch). This value is not statistically different from the threshold value determined in Experiment 1 ($t_{38} = .345$) in which letterlike shapes were used.

The results of both experiments indicate the following PFR for CURVATURE:

$$\left[\text{Functional CURVATURE:} \quad r \underset{\substack{\text{not} \\ \text{present}}}{\overset{\text{present}}{\lessgtr}} h \times 0.72\right]$$

The character height, h, was inserted in this PFR under the assumption that the PFR is scale-invariant. Note also that the PFR may be subject to contextual effects similar to those discussed by Kuklinski.[5]

3. Summary

The results of Experiments 1 and 2 are consistent with the following algorithm for determining letter labels for characters (composed of circular segments) from O-D trajectories (see Fig. XV-2):

1. The character is broken into left and right parts.
2. Each part is independently categorized as functionally straight or curved by PFR for CURVATURE.
3. The two categorizations are compared. If the two sides are categorized alike, the character is labeled O; otherwise it is called a D.

The Straight-Straight result was obtained in a different experiment not reported here; the Curved-Straight case has not been investigated in detail and hence the result indicated is only tentative.

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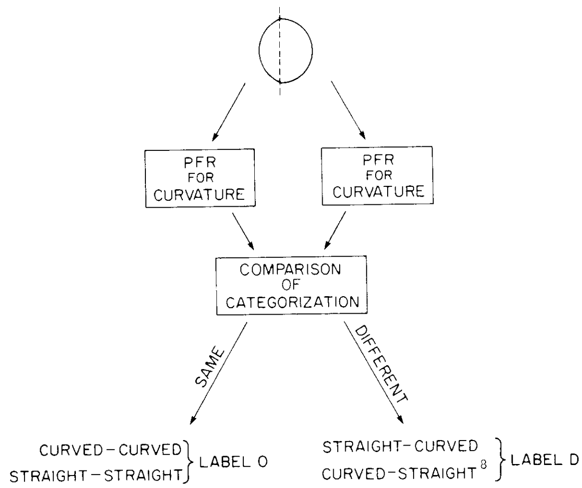

Fig. XV-2. Possible algorithm for O-D discrimination.

The model predicts that a change in the PFR for curvature would affect both the categorization boundary in a shape experiment and the labeling boundary in an O-D letter recognition experiment. Therefore a strong test of the model would be to shift the PFR (as described by Blesser et al.[4]) and to observe whether or not the shape boundary and the letter boundary move together as predicted.

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B. AUTOMATIC RECOGNITION OF THICK STROKE CHARACTERS

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Joint Services Electronics Program (Contract DAAB07-75-C-1346)
National Science Foundation (Grant ENG74-24344)

Robert J. Shillman

The functional attribute LEG has been proposed[1] as the feature that distinguishes Y from V, F from C, P from D, H from U, and A from O. In psychological experiments with thin-line characters (e.g., characters having stroke widths ≈ .15 mm), we found[2] that letter labels could be obtained by using the following physical-to-functional rule (PFR):

$$\left[\text{Functional LEG:} \quad \ell_1/L \underset{\text{not present}}{\overset{\text{present}}{\gtrless}} 0.17\right]$$

The rule states that if the physical distance from the lower end of the stroke to the intersection (ℓ_1) is greater than 17% of the entire stroke length (L), then in a neutral context the character is more likely to be called Y (or F, P, H, A) (see Fig. XV-3).

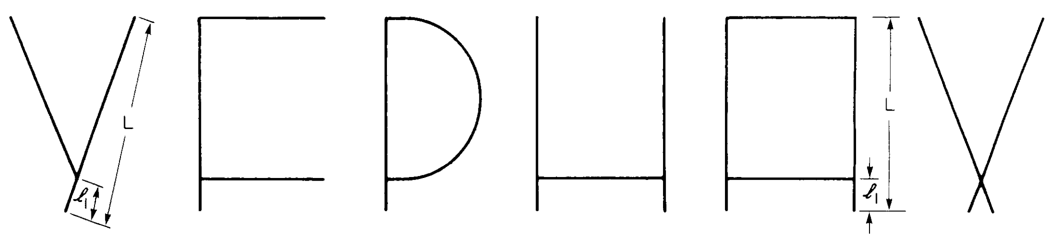

Fig. XV-3. Five characters that are ambiguous because of the transitional state of the functional attribute LEG.

When using "real life" characters, problems arise with computer implementation of this algorithm; for example, typical handprinted characters are not carefully constructed with straight lines having fine stroke width. Lines drawn with No. 2 pencils typically vary in width from .4 mm to 1.2 mm. If characters are 6.4 mm high (1/4"), we find stroke width-to-character height ratios (w/h) of 1/16 to 3/16. Figure XV-4 illustrates a typical stimulus character used by Shillman together with three other characters having more realistic w/h values. For these characters, it is impossible to apply the PFR for LEG directly, since it is not clear how to measure the length ℓ_1. In an investigation of this problem, Chow[3] found that subjects mapped thick-stroke characters from a V-Y trajectory to functionally equivalent (i.e., having the same letter label) thin-line characters consistently. Chow's data indicate that subjects compute ℓ_1/L as shown

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Fig. XV-4. A skeleton character and 3 characters having realistic w/h values.

in Fig. XV-5. Although this rule for computing ℓ_1/L is the best data fit of Chow's hypotheses, the difference between the empirical and the predicted results became greater with the increasing value of w/h. A possible explanation of this deviation is that the perceived length of ℓ_1 (as defined in Fig. XV-5) decreases with increasing stroke thickness because of an illusion.

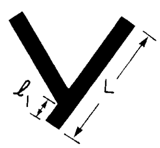

Fig. XV-5.
Measurement of ℓ_1/L on a character composed of thick strokes.

It is often observed that a fat person appears shorter than he actually is. The estimation of the heights (or lengths) of objects of different widths is a frequent occurrence in our daily lives (e.g., estimating the height of a wall vs the length of a board, estimating the length of a piece of cloth vs the length of a piece of thread). In view of common knowledge that wide objects appear shorter than narrow objects of the same physical height and in view of the great interest and effort that psychologists have accorded visual illusions,[4] it is surprising that there has been no quantitative investigation of the effect of width on the perception of length. The following experiment was carried out to investigate the hypothesis that thick lines appear to be shorter than thin lines of the same length.

Fourteen subjects (M. I. T. students) compared 16 vertical lines of various lengths and widths with a given set of 32 thin vertical lines referred to henceforth as the standard set. For each of the sixteen stimulus lines, each subject was instructed to select the line from the standard set having the same length. The sixteen stimulus lines comprised 4 sets of different widths (W = .40, 3.81, 6.35, and 8.89 mm) at each of four different lengths (L_A = 28.5, 31.0, 33.5, and 36.0 mm); the four thin stimulus lines were of the same width as the standard lines and served as controls. Each stimulus line was on a separate black-and-white photograph (13 × 10 cm). The standard set of 32 thin comparison lines was on one large black-and-white photograph (30 × 56 cm); the standard lines varied uniformly in length from 18.3 mm to 38.0 mm, were spaced 1.27 cm apart, and stood vertically from a common baseline. Four different interline separations between the stimulus line and the comparison lines were investigated (d = 2.54, 7.62, 12.7, and 22.9 cm). Four different masks were used to control the horizontal distance between

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a stimulus line and a particular standard line to which it was being compared. Each mask was constructed of white cardboard (23 × 40 cm) and had a vertical viewing window (11.4 × 1.9 cm) that was placed a fixed distance to the right of a marked position where a stimulus photograph was glued temporarily. A viewing frame kept the standard set vertical, approximately perpendicular to the line of sight, approximately 2 ft from the place where the subject was seated. By sliding the mask along a horizontal groove at the base of the viewing frame, the subject could compare the given stimulus line, which was temporarily glued to the mask, with each of the standard lines as they appeared through the viewing window. The mask-stimulus pairs were presented in random order; each subject worked at his own pace and the 64 judgments (16 stimuli at each of four different comparison distances) were completed in approximately 45 minutes.

Figure XV-6 shows the mean perceived length L_P vs the actual length L_A for each

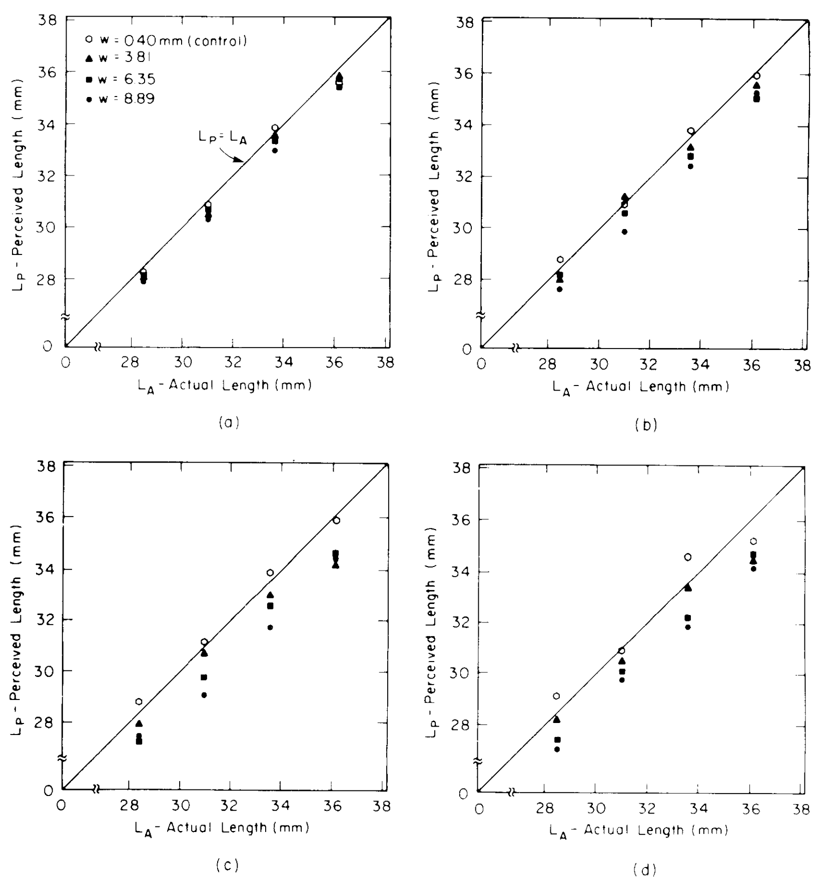

Fig. XV-6. Mean perceived length vs actual length for four different linewidths at four different comparison distances, d: (a) d = 2.54 cm, (b) d = 7.62 cm, (c) d = 12.7 cm, (d) d = 22.9 cm. The diagonal line $L_P = L_A$ is the predicted locus for accurate performance in the length perception task.

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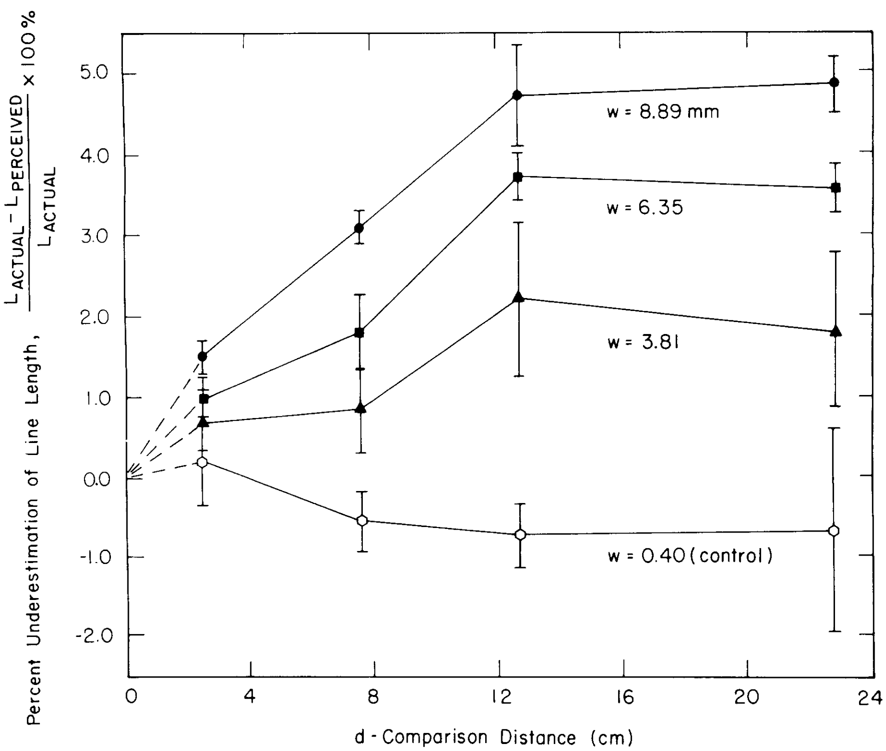

Fig. XV-7. Mean percent underestimation of line length vs comparison distance for each of four linewidths. Error bars indicate the standard deviation of the mean of 56 judgments (one judgment for each of four different line-length times for each subject).

stimulus line at each of four comparison distances d; the diagonal line is the predicted locus for accurate performance in the length perception task. The results are unambiguous; at each of the four comparison distances, the perceived lengths of the control stimuli are accurately judged ($P > .4$ by sign test), whereas the thicker stimuli are perceived as shorter than they actually are. Figure XV-7 summarizes the data; the apparent shortening of thick lines is reliable across subjects ($P < 10^{-4}$ by sign test at each of the four comparison distances) and reliable across stimuli ($P < 10^{-5}$ by sign test). The possibility that the observed illusion is due to extraneous effects, such as mode of presentation[5] or visual context,[6] is ruled out by the accurate performance on the control stimuli.

The asymptotic behavior illustrated in Fig. XV-7 is revealing; the illusion increases until ~12 cm (approximately 15° of visual angle) after which it remains constant. (The relationship between asymptotic value of length contraction and linewidth appears to be linear in the range investigated: Percent Underestimation = $.65 \times W$ (mm) $- .75$, $r = .992$ ($r > 0$, $P > .99$). The least-square line going through (0, 0) has a .50 slope.) These

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factors, together with subjects' comments, suggest two possible modes of line-length comparison. The lines could be compared by visually scanning across the tops of the lines because all of the lines rise from a common baseline; this procedure could only be relied upon for small comparison distances, and would be unreliable for larger distances. It appears that with separations greater than ~15°, subjects mentally encode the length of the stimulus line and then compare the encoded value with the standard line. The fact that subjects reported that the thick lines "looked short" indicates that the error is in the encoding process rather than in the subsequent comparison.

The data indicate that for characters having stroke widths greater than .4 mm the PFR for LEG can be applied as shown in Fig. XV-5, but the threshold value must be modified to take into account the perceived shortening of ℓ_1 in the following manner:

$$\left[\text{Functional LEG } \ell_1/L \quad \begin{matrix}\text{present}\\ > \\ < \\ \text{not} \\ \text{present}\end{matrix} \quad \frac{0.17}{(1-.005\ W\ \text{mm})}\right]$$

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C. AUDIO RESPONSE FOR REMOTE TERMINALS

Joint Services Electronics Program (Contract DAAB07-75-C-1346)

Jonathan Allen

The design of two special processors has been completed, and one has been constructed. First, we have constructed a parameter generator processor that converts a narrow phonetic transcription of the utterance to a set of vocal-tract model control parameters. This processor is designed around the AM2901 microprocessor, and uses 4K RAM memory for both program and data. We are now recasting the parametric algorithms in terms of the new instruction set.

Second, we have designed an all-digital terminal analog synthesizer, which serves as a vocal-tract model. This design uses serial arithmetic, retains 24 bits of precision, and is capable of exercising up to 32 second-order difference equations at a 10-kHz sample rate. This capability is controlled by a small microprogram, so that the same hardware can support several different models. Implementation of the 90-dip circuit should be complete by the third quarter of this year.

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