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PROJECT STRETCH

File Memo # 59

SUBJECT: Character Determination

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INTRODUCTION: This memo is an extension to Project STRETCH file memorandum #54 on shape and character recognition by J. C. Logue, dated January 4, 1957. This memo contains:

1) A discussion of and a solution for the problem of merged characters.

2) Advantages of the image dissector over the cathode ray tube in the optical portion of the character recognition machine.

3) Advantages and disadvantages of a magnetic drum when used for storage of continuous signals.

4) A discussion of synchronization and character determination circuits.

5) Information about the parametric functions of characters, obtained by programming the 704.

USE OF ELECTRIC SHUTTERS FOR MERGED LETTERS

The problem of merged letters appears when using typewriters. Using the regular I. B. M. electric typewriter to type lower case letters in combination with the lower case m; the following letters merged with m:

a, d, g, h, k, x, v, n, w, r, y, u, i, p, m.

The same typewriter was used to type all combinations of numbers. It was found that the 4 merged with the 4 and the 0 merged with the 8. The 0 and 2 combination and the 4 and 8 combination were very close to merging. Using the I. B. M. Executive electric typewriter the following lower case letters merged with the lower case m:

h, k, y, u.

There is no merging between numbers on the Executive electric typewriter.

The method of shape and character recognition proposed by Mr. J. C. Logue (refer to file memorandum #54) requires that each character be distinct and separate from any adjacent character. This is necessary since the information needed for recognition is obtained by following along the outside perimeter of the character. If the "following circuit", described in Mr. Logue's report, came to a combination of letters that were merged, it would not see the individual characters but would see the merged characters as one resultant character. For example, if handwriting was put into the proposed character recognition machine, each word would appear as an entity. In Mr. Logue's character recognition scheme, the "following circuit" knows when it is on the perimeter of a character because the perimeter has block (ink) on one side of it and white (paper) on the other side of it. This is the information actually used to control the "following circuit". Merged letters present the problem that what should be white is black. The most obvious answer to this problem is to make what is black, but should not be black, white. One method to achieve this is to use electronic shutters to block out the undesired character. For example, if two characters were merged such as T and H, i. e. (TH), it would be known they were merged because of the inability to recognize (TH) as a single character. It would also be known that the left side was not in error since the machine was recognizing characters in a line from left to right and the character previous to T had been recognized. Then, it becomes apparent that the shutter should move in from the right hand side of the merged characters. The shutter moves at a uniform velocity to the left until the left hand character is recognized, the shutter locks onto this position. Then, the shutter reverses itself; where it was blocking off everything to the right of its edge it now blocks off everything to the left of its edge. Thus, the left hand edge of the second merged character is defined and can be readily recognized. If there are three consecutive letters merged, then it would be necessary to bring a shutter from the right for the second character as well as keep a shutter on the left hand edge of the second character.

An electronic shutter would merely be a blanking circuit that would be actuated whenever the beam in the cathode ray tube was beyond the set shutter position. This blanking circuit would shunt the optical system and send a current thru the output resistor in the photomultiplier circuit whenever the beam in the cathode ray tube was beyond the edge of the shutter. Thus everything would appear white to a beam that was beyond the edge of the shutter.

ELECTROSTATIC IMAGE DISSECTOR

File memorandum #54 by J. C. Logue considers only a flying spot scanner as the electro-optical part of the character recognition system. Since that memorandum was written, the group has been informed of an electrostatic image dissector that is under development by DuMont. The substitution of an electrostatic image dissector into the character recognition system would eliminate two problems inherent in a flying spot scanner. One problem encountered when using a flying spot scanner is that the phospher of the cathode ray tube has a persistence characteristic that limits the speed of operation; the image dissector has no persistence difficulties. The flying spot scanner also requires a light tight cover over the optical portion; this is not necessary when using an image dissector. If an image dissector with linear electrostatic control is available, it should give better performance then a flying spot scanner.

MAGNETIC DRUM STORAGE

In file memorandum #54, Mr. J. C. Logue describes the circuits necessary to generate parametric functions by following the perimeter of the characters. Once we have these parametric functions we must determine which character the function represents. The method of comparison that will be used is to match by an analogue method, the parametric functions that are generated with stored parametric functions.

A storage medium is necessary to store the standard parametric functions. The storage medium that appears to be best suited to the requirements of the character recognition scheme is the magnetic drum. The advantages of a magnetic drum over other storage media shall now be discussed. The information being stored is a continuous signal; therefore, our storage medium must be capable of storing a continuous signal. This eliminates storage media that are of a digital nature, such as magnetic core memories. It is very desirable that the storage medium be of a cyclic nature, since the parametric function that is generated shall be cyclic. If the storage medium is cyclic, then it is only necessary to store one cycle of the parametric function. A drum is inherently cyclic while tape is not inherently cyclic. When a continuous signal is recorded, it is necessary that it is recorded at a constant speed, otherwise, a distortion known as "wow" is introduced. This type of distortion could not be tolerated in the proposed character recognition scheme. This consideration favors drum storage over tape storage. The ease of erasing old information and writing new information is an advantage that a magnetic drum has over such other drum systems as photographic, mechanical grooves and photoelectric.

When storing a continuous signal on a magnetic surface, there are certain characteristics of magnetic storage that affect the fidelity of reproduction. These are:

1. The wider the recording track is, the greater is the signal to noise ratio.

2. The highest frequency that can be recorded accurately is is a function of the relative speed between the recording head and the magnetic surface.

3. The frequency response is not constant.

4. The closer the recording head is to the surface, the smaller is the spacing loss. Spacing loss results in attenuation of higher frequencies.

To illustrate the 2nd and 3rd characteristics, figure 1 is a typical frequency response curve of a magnetic medium.

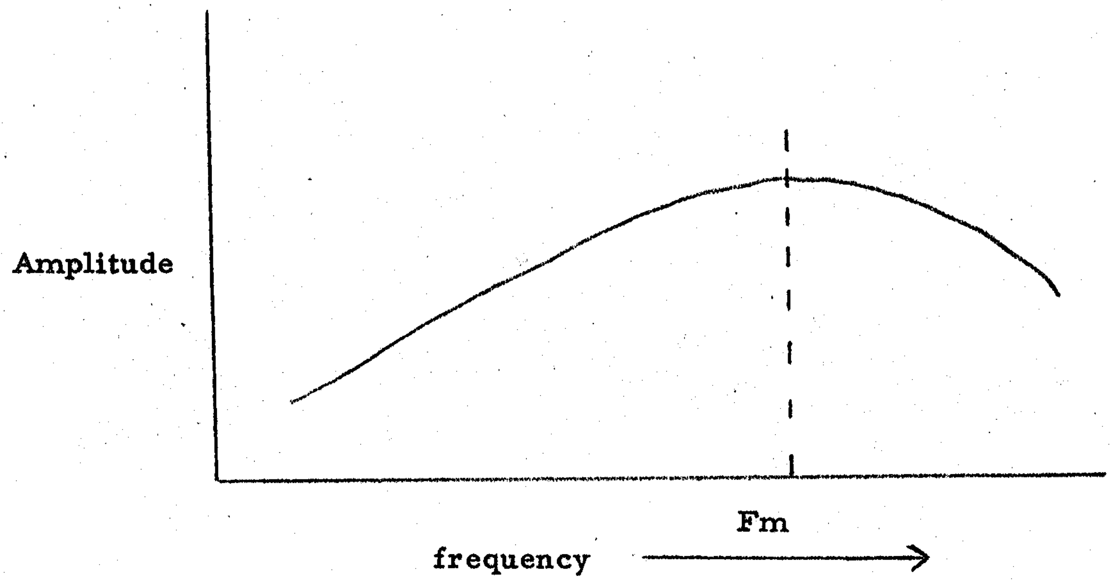

Figure 1: Frequency Response Curve for Magnetic Medium

Due to the second characteristic, the frequency which has the highest output in Figure 1 (Fm) increases with an increase in the relative speed between the recording head and the recording medium. This means a high speed drum is necessary for wide bandwidth. The necessity for a high speed drum to obtain wide bandwidth does not present a new problem since a high speed drum is a requirement for a high character recognition rate. This requirement shall be explained later. The third characteristic of a non-constant frequency response requires that all parametric functions of the characters be distorted in the same manner before a comparison is made. Therefore, since the standard parametric functions are stored on the drum, then the parametric function of the character to be recognized must be recorded on the drum before a comparison is made. Equalization is out of the question since a minimum phase network introduces phase distortion and it is essential to preserve the waveform of the parametric function. Since it is necessary to record the parametric function before comparing it, the recognition rate will be dependent on the recording time. Only one parametric function may be recorded on a track of the drum because a continuous signal must be read out. Therefore, the minimum recording time will occur when the frequency of the drum equals the fundamental frequency of the parametric function. At present, a fundamental frequency of one kilocycle is being considered. This would require a drum with a speed of 6×10^4 rpm if only one cycle per track is to be recorded. Development word on a drum with speeds up to 8×10^4 rpm is being conducted at the Endicott Product Development Laboratory.

Based on the first characteristic it is necessary to use a wide track to improve the signal to noise ratio.

The fourth characteristic requires that all recording heads and all reading heads are the same distance from the recording surface, in order to obtain the same frequency characteristic for all heads.[1]

The problem of getting the standard parametric functions onto the drum is easily solved. These can be obtained directly from the character recognition machine by putting into the machine a paper containing all characters that are to be recognized. The machine will generate the parametric functions of the characters and these can be stored on the drum. The only requirements are that the characters be in the right sequence and that the impulse train necessary for phase adjustment (described in the next section) be on the drum. This method of obtaining the standard parametric functions in the same manner as the parametric functions that are to be recognized assures that recognition shall be independent of any consistent distortion of characters that the recognition machine introduces.

SYNCHRONIZATION

As stated previously, the parametric function is obtained by following the outside perimeter of the character. Since it is necessary for all characters to have the same fundamental frequency for the purpose of simplifying recognition and since the perimeters of different characters are not the same length, it is necessary to have a variable following rate. This

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1. For a complete discussion of spacing loss refer to the Bell System Technical Journal volume 30, page 1145.

is accomplished by having a variable gain amplifier before the integrator in the scanning circuits. (Refer to Figure 10 in Project STRETCH File Memorandum #54). This variable gain amplifier is controlled by a feed-back circuit around the amplifier and integrator. (Refer to Figure 2A.) The feed-back circuit consists of a filter which filters out the fundamental frequency of the parametric function and a discriminator circuit that gives a D. C. output that is proportional to the difference between the frequency of the input signal and the frequency for which the discriminator is tuned. This feed-back circuit will give all characters the same fundamental frequency. Synchronization in phase between the following circuits and the storage drum is necessary. This is accomplished after the fundamental frequency has been set by another feed-back circuit around the variable gain amplifier and integrator. The phase of the drum is used as the standard and is set up by having a train of positive impulses; one impulse every $2\pi/n$ radians along the drum, where n corresponds to the number of cycles of the parametric function recorded per drum track. The feed-back circuit consists of a filter, to filter out the fundamental frequency of the parametric function; a circuit that makes a square wave out of the fundamental frequency by clipping and amplifying it; a differentiator circuit that turns the square wave into a train of alternating impulses and then a flip-flop that has the train of impulses from the differentiator as one input and the train of impulses from the drum as another input. From this flip-flop a pulse is available whose period of duration is the same as the difference in phase between the two trains of impulses. This impulse output is then used to blank the variable gain amplifier. With the variable gain amplifier blanked, the "following circuit" is blanked for the duration of the pulse and thus the two signals will be in phase when following starts again. Refer to Figure 2A for the block diagram of the phase adjusting circuit.

ERROR MEASURING CIRCUITS

Two methods of error measurement have been evaluated. One is the mean square error; i. e.

$$\bar{e} = \frac{1}{T} \int_{0}^{T} (f_{\rho}(t) - f_{d}(t))^2 \, dt$$

and the other is mean absolute error; i. e.

$$\bar{e} = \frac{1}{T} \int_{o}^{T} \left| f_o(t) - f_d(t) \right| dt$$

From the circuit viewpoint, the mean absolute error method appears to be better. The circuits necessary to measure mean absolute error are simple and can be constructed to be accurate. For the mean absolute error, where $f_o(t)$ is the standard reference signal; $f_d(t)$ is the unknown signal and T is the period of comparison; we may use a differential amplifier followed by a full wave rectifier which feeds an averaging integrator. The output from the averaging integrator may then be fed into a voltage comparing network to decide whether the error is within set limits. A block diagram of a circuit to measure mean absolute error is given in Figure 2B.

DATA OBTAINED FROM PROGRAMMING THE 704

Several programs have been written to test the feasibility of the method of recognition. The primary purpose was to determine if harmonic content is sufficient for recognition. Programs have been written to fit a Fourier series to vertical or horizontal deflection in terms of time and to compare characters on the basis of these fitted curves. The fitting program accepts a sequence of points around the circumference of a figure, computes the distance between these points determining their separation in time since the following beam will have uniform velocity, fits parabolas thru each three consecutive points and evaluates the analytical integrations of the product of the fitted parabolas and the proper trigonometric functions to get a Fourier series expressing altitude in terms of time. The resulting curve is normalized so that the amplitude of the fundamental is unity and its phase is zero.

After the normalized Fourier series is computed comparisons of the various characters are performed by either of two methods - the average separation of the two curves which is obtained by integrating the absolute value of the difference between two series over a complete cycle and the mean squared separation which is obtained by integrating the squared difference over a complete cycle. A program has been prepared which fits an unknown curve to a set of standard curves by both methods printing out the best and second best fits. The program evaluates the integral numerically using the trapezoidal rule. The mean squared difference can be computed by an analytical integration. A second program evaluates the analytical integration of the difference squared of two Fourier series. This program takes much less machine time. The two methods are reasonably comparable in selecting best fits. A third program will print out points along a curve. This was used to see how well a y(t) function composed of 10 harmonics fits the curves represented.

Twenty-one alphabetic characters and two numerals have been examined so far. Series of 10 harmonics have been fitted and each compared to every other one to determine the closest pairs. A table of data obtained follows:

	Mean Absolute Difference		Mean Square Difference	
Character	Best Fit	Difference*	Best Fit	Difference*
B	D	.022	D	.00082
D	B	.022	B	.00082
O	D	.057	D	.0044
P	B	.093	B	.032
2	Z	.13	Z	.030
Z	2	.13	2	.030
5	B	.16	D	.040
Q	D	.18	D	.046
S	B	.18	B	.049
R	A	.19	A	.149
A	R	.19	R	.049
E	P	.20	P	.054
C	S	.19	S	.061
F	C	.30	C	.13
G	R	.32	R	.16
H	G	.36	C	.17
T	Y	.33	P	.17
Y	T	.33	F	.19
N	H	1.11	H	1.56
U	V	1.81	V	3.95
V	U	1.81	U	3.95
M	G	1.85	R	4.28
W	V	2.07	T	6.33

*Difference is based on amplitude of fundamental normalized to unity.

The first column in the table gives the character whose parametric function was compared with the parametric functions of the other characters. The second column gives the character whose parametric function was the closest fit to the parametric function of the character in the first column. The mean absolute difference of the two parametric functions was the method of comparison. The third column gives the magnitude of the mean absolute difference.

Columns four and five contain data obtained when the method of comparing parametric functions is the mean square difference.

The pairs of characters that fit very closely when using only ten harmonics; e. g. B and D, were compared using twenty harmonics. The mean differences were changed only a negligible amount.

More data must be obtained to determine the best way to compare the parametric functions of characters. Other methods of comparison and of setting up the parametric function are being investigated at the present time.

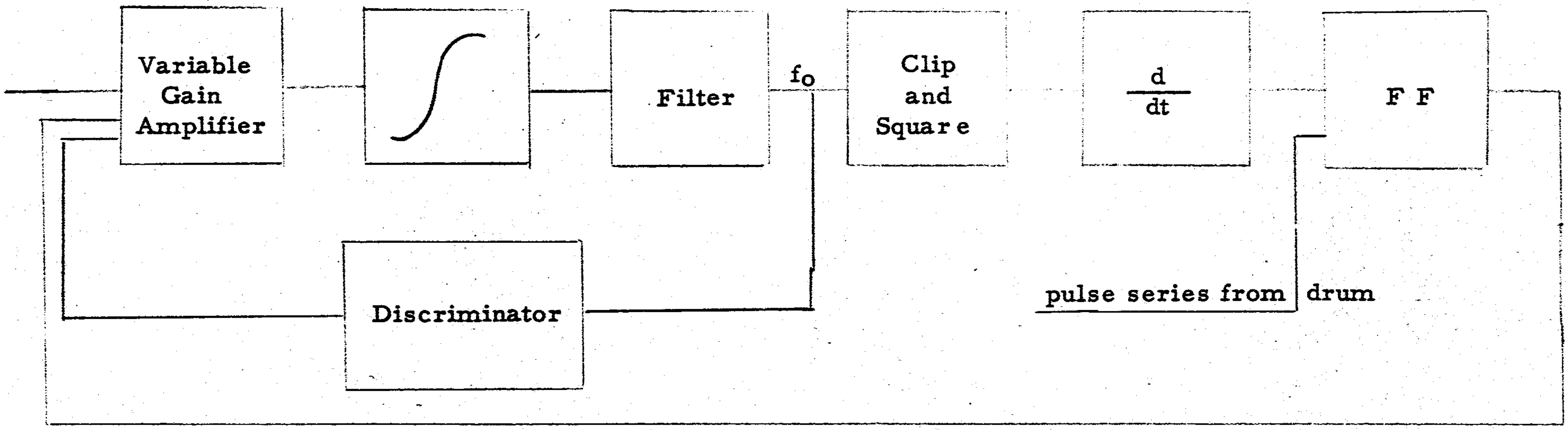

Figure 2a: Simple Block Diagram of Frequency and Phase Control Circuits

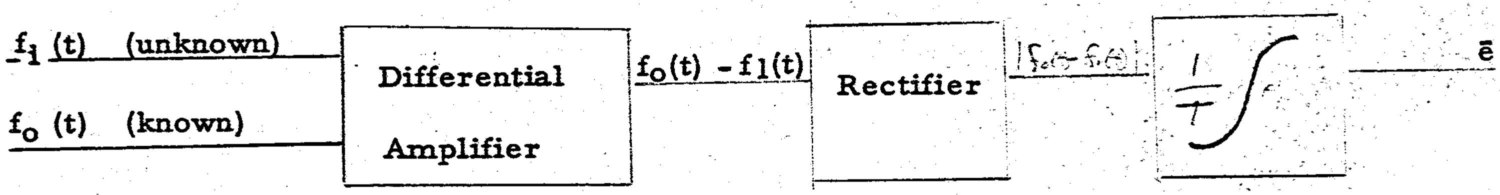

Figure 2b: Block Diagram of Circuit to Perform the Operation: $\bar{e} = \frac{1}{T} \int_0^T \left| f_o(t) - f_1(t) \right| dt$