XIII. COGNITIVE INFORMATION PROCESSING*

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Prof. M. Eden
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Prof. W. F. Schreiber
Prof. O. J. Tretiak
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G. L. Wickelgren

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D. Caldwell
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A. PICTURE PROCESSING

1. SCANNER DISPLAY (SCAD)

Purpose of the Equipment

The Scanner-Display system, called SCAD, is a device for communicating between computers and pictures. In its present form it can accept transparencies, measure the transmission at various points on the transparency, and convert this to a digital number. It can also accept digital data and produce pictures from it.

The device is a transducer between digital computers and pictures. SCAD can be operated with digital tape or with a computer. When SCAD is operated with tape, it can either scan transparencies and write the digital information on a magnetic tape, or it can read a digital magnetic tape and display the data from it on a CRT. The display can be viewed and photographed. When SCAD is operated by a digital computer, the computer can either interrogate the transmittance of a transparency at points chosen by the computer, or it can display information, again with brightness and coordinates chosen by computer. The scanner can measure color, as well as brightness.

SCAD measures brightness and displays data over a raster of discrete points. The raster may contain 1024 points along each of two orthogonal dimensions, although fewer points than this may be used. The resolution of the scanner and display depends on the components used in these units, and may be more or less fine than the spacing of the

*This work was supported in part by the Joint Services Electronics Programs (U. S. Army, U. S. Navy, and U. S. Air Force) under Contract DA 36-039-AMC-03200(E), and in part by the National Science Foundation (Grant GK-835), the National Institutes of Health (Grant 2 PO1 MH-04737-06), and the National Aeronautics and Space Administration (Grant NsG-496).

raster points. Brightness information can be quantized to 8 bits (256 levels).

Block Diagram

A symbolic block diagram of SCAD is shown in Fig. XIII-1. The transparency to be scanned is placed in the scanner. The picture being displayed by the system may be viewed on the monitor or photographed with the display unit. The deflection amplifiers accept the deflection signal from the central control unit, and generate deflection currents for the scanner, display, and monitor. The analog section generates voltages for controlling the intensification of the scanner, the display, and the monitor, and accepts and provides control and brightness signals from and to the central control unit.

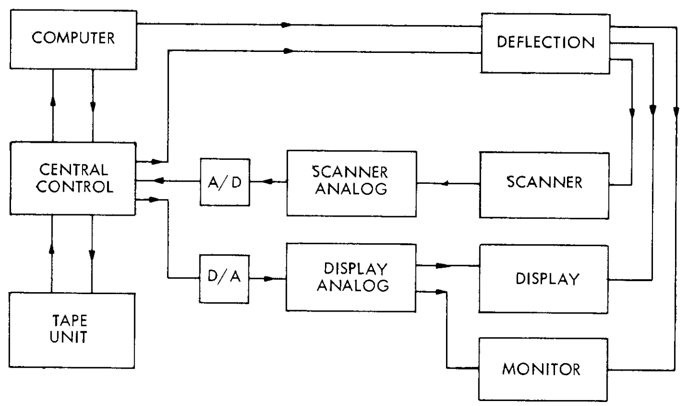

Fig. XIII-1. SCAD system diagram.

The central control unit is the clearing house for data flow between the analog section and the tape unit or the computer. It also sequences the operation of the deflection in the scanner and the display. When SCAD is being operated with a tape unit, central control also generates signals that control tape motion.

a. Scanner Block Diagram

A symbolic diagram of the Scanner is given in Fig. XIII-2. A spot of light from the cathode-ray tube face is imaged on a transparency. The light passing through the transparency is collected by the condenser and is sent through a sequence of dichroic mirrors. The mirrors split the light spectrum into three bands, and each band is sent to a different photomultiplier.

To counteract variations in the light given off by the cathode-ray tube part of the light coming from it is taken by a beam splitter and sent to a photomultiplier tube. The signal from this photomultiplier is used to control the CRT drive.

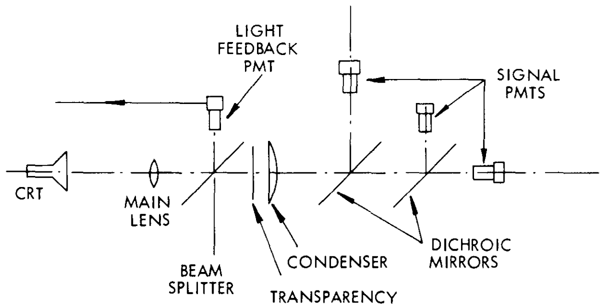

Fig. XIII-2. Scanner symbolic diagram.

b. Display Unit

A symbolic diagram of the Display Unit is shown in Fig. XIII-3. The Display cathode-ray tube is mounted underneath a Polaroid MP-3 copy camera. A partially reflecting mirror is interposed between the camera and the CRT and a portion of the light coming from the CRT falls on a photomultiplier tube. The signal from the photomultiplier tube may be used to adjust the drive to the CRT.

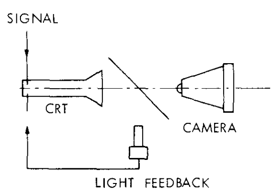

Fig. XIII-3. Display unit.

c. Monitor

The Monitor consists of just a cathode-ray tube with a long-persistence phosphor. The same brightness information that is supplied to the Display is also displayed on the Monitor.

d. Analog Section

The analog section associated with Scanner operation amplifies the signal from the scanner, puts this through an appropriate nonlinear amplifier, and presents this signal to the A/D converter. It also generates the voltages necessary to operate the Scanner cathode-ray tube.

The Scanner Amplifier portion of the analog section is shown in Fig. XIII-4. The scanner is operated in intermittent fashion: the CRT is normally blanked, and it is

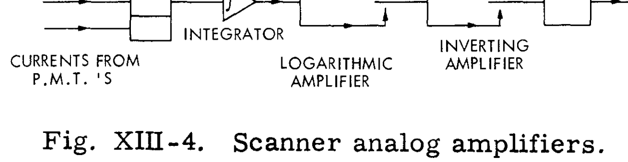

Fig. XIII-4. Scanner analog amplifiers.

unblanked only when one wishes to measure the transmittance of some point on the transparency. The anodes from the three pickup PMT come into a gate which permits current from only one PMT to enter the integrator. The tube is blanked at the end of the intensification period. The output of the integrator is fed into an amplifier chain that can provide one of four transfer characteristics. Let S be the final signal output, T the transmittance of the transparency, and k a variable, proportional to the gain of the variable gain amplifier, and A a constant equal to the peak value of the signal. The four transfer functions are

1. Linear normal

$$S = kT$$

2. Linear inverted

$$S = k(A-T)$$

3. Log normal

$$S = k(\log T)$$

4. Log inverted

$$S = k(A - \log T)$$

Log normal is the usual transfer function for operating the scanner. The "contrast" is controlled with the variable amplifier gain. The "brightness" is adjusted by setting the PMT supply voltage.

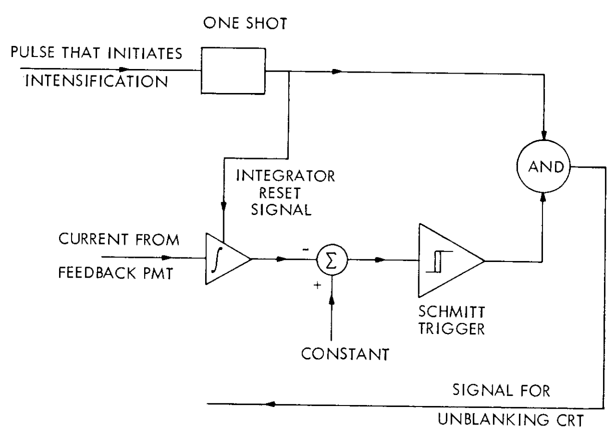

Fig. XIII-5. Scanner light feedback.

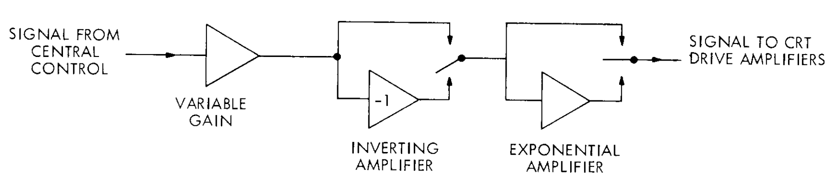

Fig. XIII-6. Display analog amplifiers.

It is important that the cathode-ray tube supply the same amount of light to each scanned point. The scheme for insuring this is shown in Fig. XIII-5. A pulse from the central control section initiates the intensification by putting a one-shot into a metastable state. While the tube is unblanked the current from the feedback PMT is integrated. The CRT is blanked when the integrated signal reaches a predetermined level or when the one-shot leaves the metastable state.

The schematic description of the amplifiers used to process the signal for the Display and for the Monitor is shown in Fig. XIII-6. Four transfer functions can be selected by interconnecting the various amplifier components. These are called: linear normal, linear inverted, exponential normal, and exponential inverted. The transfer functions of these modes are inverse to the corresponding transfer functions of the scanner.

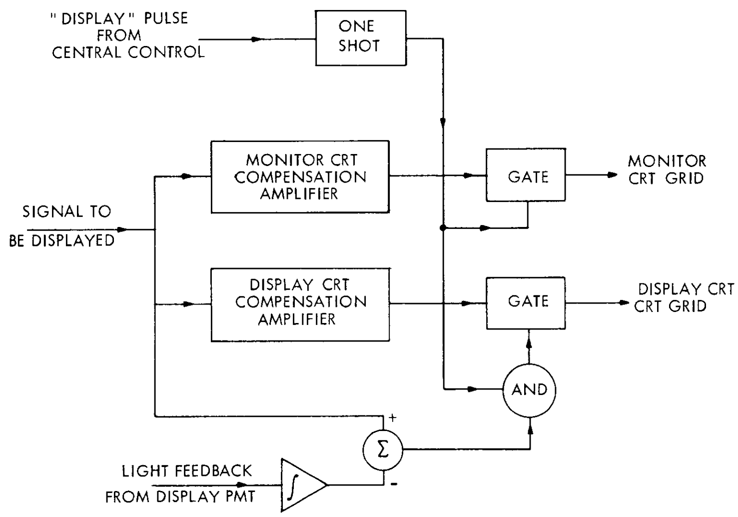

Fig. XIII-7. Display light feedback and monitor drive.

The circuits for driving the display and monitor cathode-ray tubes are given in Fig. XIII-7. The same signal is applied to the monitor and the display CRT. Since the transfer function of each tube is different, each tube has its own compensating amplifier. Both tubes are blanked most of the time. They are unblanked whenever this section receives a "DISPLAY" pulse from central control. This pulse triggers a one-shot. The monitor is unblanked as long as the one-shot is in the metastable state; the unblanking period for the display is controlled in the same way as in the scanner CRT. Light from the display unit is sampled by a PMT, the current from this tube is integrated, and this integral is compared with the signal to be presented on the display. The display tube is blanked when the one-shot leaves the metastable state or when the light feedback signal exceeds the input signal, whichever event occurs sooner. The controlling scheme is intended to produce a linear relation between the exposing light from the face of the display tube and the signal at the input to Fig. XIII-7.

e. Deflection Section

The Deflection section contains flip-flop storage for the display coordinates, D/A converters for changing the digital coordinates into analog voltages, and power amplifiers for generating deflection currents for the CRT. Control amplifiers between the D/A converters and the power amplifiers enable one to change the correspondence between the digital number and the deflection coordinates. Gain and bias controls for these amplifiers are located on the main panel. The general arrangement of the Deflection system is shown in Fig. XIII-8.

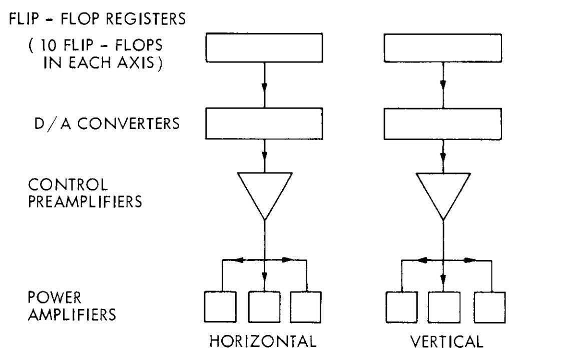

Fig. XIII-8. Deflection system symbolic diagram.

The flip-flop registers that hold the display coordinates perform several functions. When the equipment is operated by the computer, the registers can receive data directly from the computer. Under tape operation, the registers operate as counters. A schematic diagram of these counters is given in Fig. XIII-9. When SCAD is operated under local control, the scanning raster

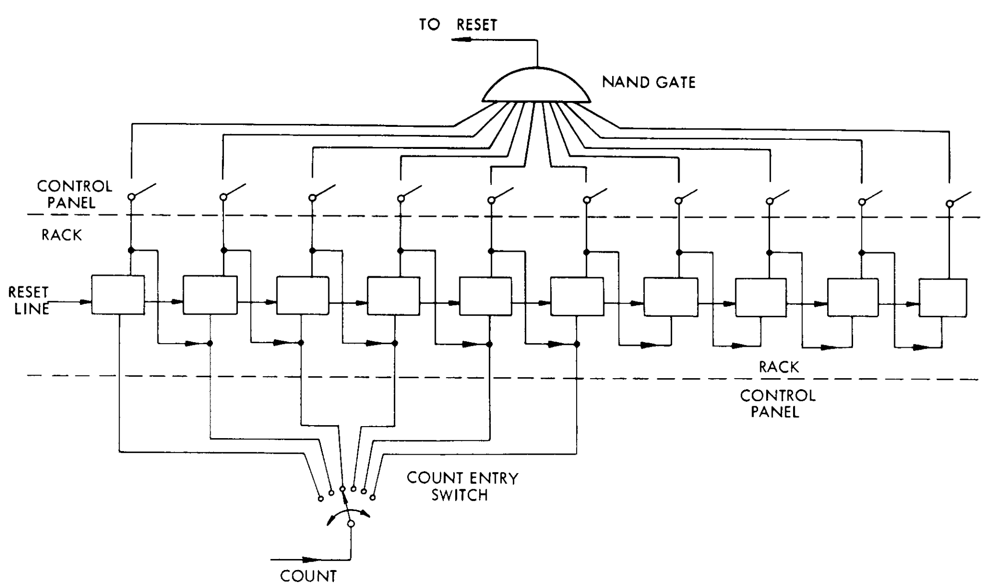

Fig. XIII-9. Counter interconnection for conventional noncomputer operation.

is determined by the counter settings. The two banks of counters are connected in tandem: the "clock pulses" are fed into the low-order end of the horizontal counter, and the "overflow" from the horizontal counter goes into the vertical counter. Both counters count up, and they start from zero. The raster is controlled by setting a number at which the counter is reset to zero, and by selecting the flip-flop which receives the "clock pulses." The last control, called "count entry," determines the fineness of the raster. Were the register allowed to go to a full count, one could change the raster resolution by a power of two with this control. Finer variations of the raster size are obtained with the above-mentioned reset control. The number at which the counter is reset is set up with a bank of toggle switches on the control panel.

The circuitry of the counter is such that the counter can be made to count either up or down. The direction of counter indexing is varied in the computer mode; under usual conditions of operation under local control, the direction of incrementing is fixed in both counters.

f. Central Control

The Central Control section performs a variety of functions. The operation of these is so interrelated that it is not convenient to represent this in block diagram form. We shall now describe some of the components contained in the Central Control section and some of the signals that are generated by it.

The Central Control section sequenced the operation of the other units that have been described. It generates command pulses to the Scanner, Display, etc. in response to signals from these units. For example, when the equipment is being used to play back tapes, the tape unit emits a pulse whenever a word of data is available. Central Control responds to this pulse by copying the data to the signal D/A converter and by displaying the data. After the Display indicates that the data have been displayed, Central Control issues a pulse that causes the counters to advance.

g. Test and Alignment Section

Several switches are connected to sundry test points in the SCAD. By operating these switches, one can select many of the important signals inside the SCAD and connect these to an oscilloscope. This facility is useful for aligning the signal from the scanner or to the display, and it is of some help in troubleshooting the equipment. The test section also contains some switches and circuitry that feed the deflection counter bits into the D/A converter, so that one can display a step hedge test signal.

h. Analog-to-Digital Converter

The analog signal produced by the scanner must be digitized before it can be sent to either the Tape Unit or the Computer. This is done with a bit-by-bit A-to-D converter.

The outputs are on parallel lines. The converter is preceded by a circuit that follows the input signal whenever the converter is quiescent, but holds the input voltage to the converter fixed when the unit is encoding this voltage.

i. Digital-to-Analog Converter

The digital signals coming from the Computer or from the Tape Unit are decoded into an analog voltage by the Signal Digital-to-Analog converter. This unit consists of a bank of 8 flip-flops which drives an 8-bit resistive ladder. The decoded voltage from the ladder is buffered with a unity-gain amplifier.

Each flip-flop in the register can be set from one of three sources. The data come either from the outputs of the A-to-D converter, from an external unit such as Tape or Computer or from the deflection counters.

Operating Modes

SCAD can be operated in one of several distinct modes. The mode is selected with the mode-control switch on the control panel. The internal programming for the mode controls is done through both the mode control switch and internal logic actuated by voltages that are generated with the switch.

Five principal modes are available. The modes fall into three types. The mode types and the actual modes are tabulated in Table XIII-1. The three types refer to different ways of obtaining data for the operation. In the two direct modes, the equipment takes the data obtained by digitizing the scanner output into the D/A converter and displays it. The two direct modes are called Direct Fast (DF) and Direct Slow (DS). The

Table XIII-1. SCAD operating modes.

Direct Modes:	
	1. Direct Fast
	2. Direct Slow
Tape Modes:	
	1. Record
	2. Playback
Computer Mode:	
	1. Computer

difference between them will be explained below. The two different tape modes are called Record and Playback, and are used to display pictures recorded on tape and to record data from the scanner onto tape. In the Computer Mode, the equipment is operated by the computer.

We shall now discuss the modes in terms of the control signals that the Central Control section generates to operate the equipment in each mode. The sequencing section generates these commands in response to information that is received from subunits, such as the scanner and the converters, or from external devices such as the tape unit.

The command signals and "busy levels" used in SCAD are listed in Table XIII-2. We differentiate between a command, which is usually a pulse that initiates some sort of operation, and status levels, which indicate that a certain unit is performing its operation.

Table XIII-2. Command signals and "busy levels" used in SCAD.

Subunit	Command	Busy level	Remarks
A/D Converter	Convert	Converting	Convert Always follows end of Intensifying
D/A Converter	A/D to D/A	Copying	
	EXT to D/A	Copying	
	TEST to D/A	Copying	
	Reset D/A	(None)	Always occurs at end of displaying
Deflection	Advance Hor	Deflecting	
Counters	Advance Ver	Deflecting	
	Reset Hor	Deflecting	
	Reset Ver	Deflecting	
Display Unit	Display	Displaying	
Scanner	Intensify	Intensifying	
Tape Unit	Data Read		Signifies that the tape unit has some data waiting for SCAD
	Data Request		Tape unit calls for data from the scanner
	Data Ready		SCAD has data available for the tape unit
	Write EOR		SCAD requests the tape unit to write an EOR

An example of a command is DISPLAY: this is a pulse that causes the Display unit to display the data currently being put out by the D/A converter at the coordinates currently in the deflection registers. The "busy level" associated with this operation is called DISPLAYING. In the sequel we shall describe the chain of events that occurs in each mode, and comment on some of the items worthy of special note.

a. Matters Common to All Noncomputer Modes

In the noncomputer modes, the data format (which means the number of scanning lines per picture and the number of points per line) is determined by the counters. The number of points through which the horizontal or the vertical counter goes can be selected with the switches on the control panel. Under usual conditions, the count pulses enter the horizontal counter, and the overflow from the horizontal counter advances the vertical counter.

Whether or not the system is running is determined by the RUN flip-flop. This flip-flop is set by the start pushbutton. It can be reset by the stop pushbutton or by the overflow pulse from the vertical counter which will reset RUN if the single-multiple switch is in the single position; otherwise, the equipment will keep running.

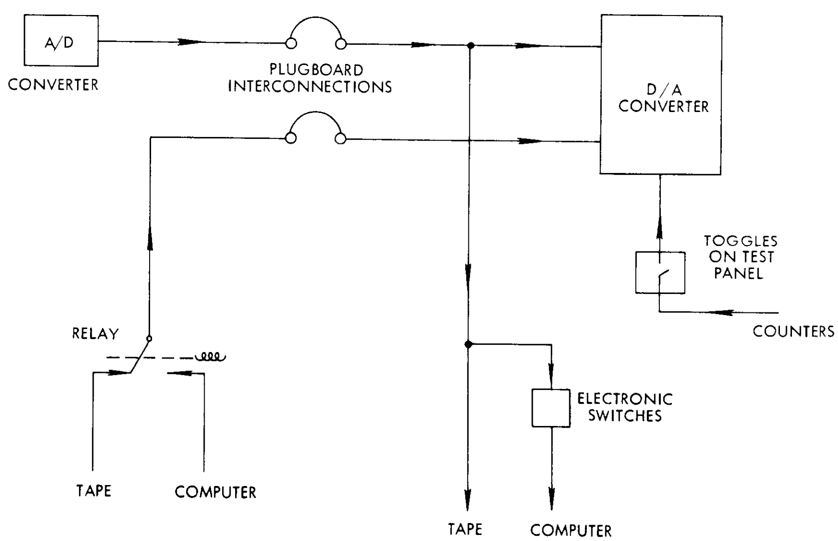

Fig. XIII-10. Digital signal-flow symbolic diagram.

The paths arranged for the flow of the digital data in the SCAD are shown in Fig. XIII-10; The noteworthy detail of this diagram is that all of the digital data go through a plugboard. This enables one to make some limited changes in the format of the data. For example, one may display, in the direct modes, pictures quantized to less than the 8 bits available from the A/D converter or display the individual bits of the digitized picture.

b. Direct Fast Mode

The Direct Fast Mode is set up primarily for aligning and adjusting the Scanner and the Display. In this mode, the data from the scanner is transmitted directly to the display unit. The sequence of events in this mode is shown in Fig. XIII-11. In this figure, the name of a busy level followed by a bracketed E is used to represent the end of the activity associated with this level. For example, Displaying (E) represents the end of the displaying interval.

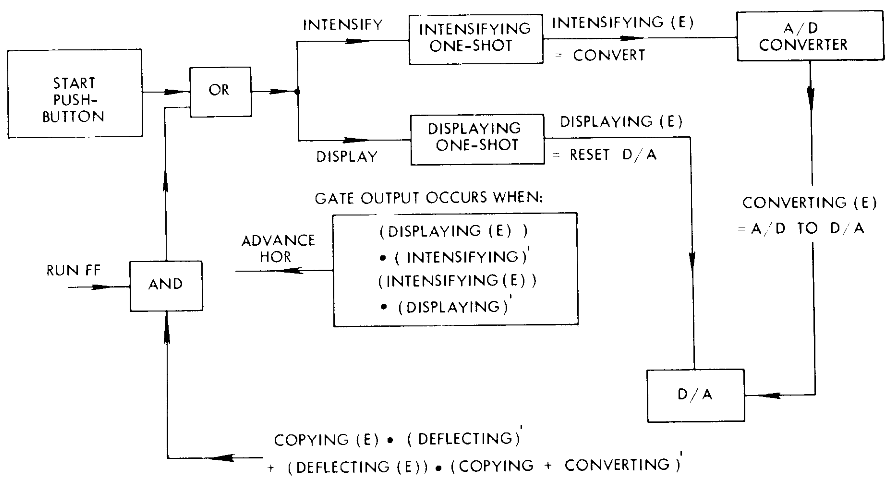

Fig. XIII-11. Direct fast-mode symbolic timing chart.

Please note that since the deflection coordinates of the scanner and the display unit are identical, the displayed picture in the Direct Fast mode does not appear at the same location as the original picture, but is "delayed" one dot. With the usual line-by-line scanning pattern, this misregistration is hardly noticeable.

c. Direct Slow Mode

The Direct Slow Mode can be used for the same purposes as the Direct Fast Mode. In the DS mode the data from the scanner is displayed at the coordinates from which it was obtained. The sequence of events for this mode is given in Fig. XIII-12.

d. Record Mode

In the Record Mode (refer to Fig. XII-13), the encoded data from the scanner are sent to the tape unit, which proceeds to record them. The timing in this mode is under control of the tape recorder: the tape recorder sends "Data Request" pulses to SCAD.

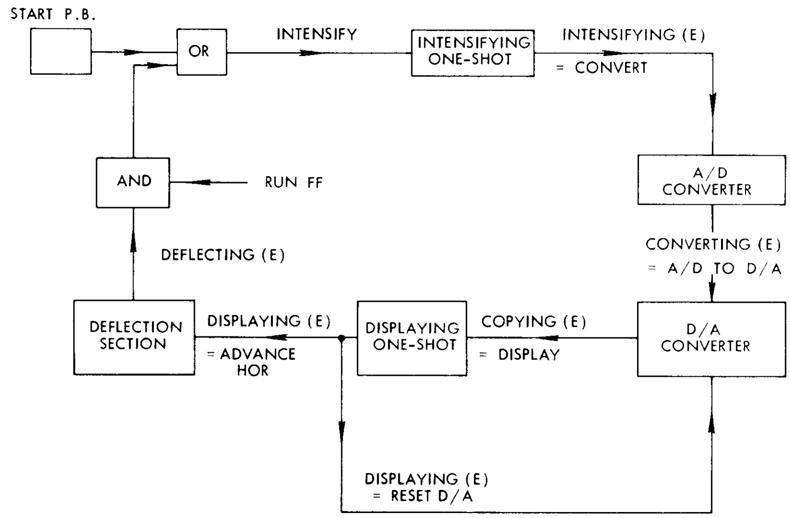

Fig. XIII-12. Direct slow-mode symbolic timing chart.

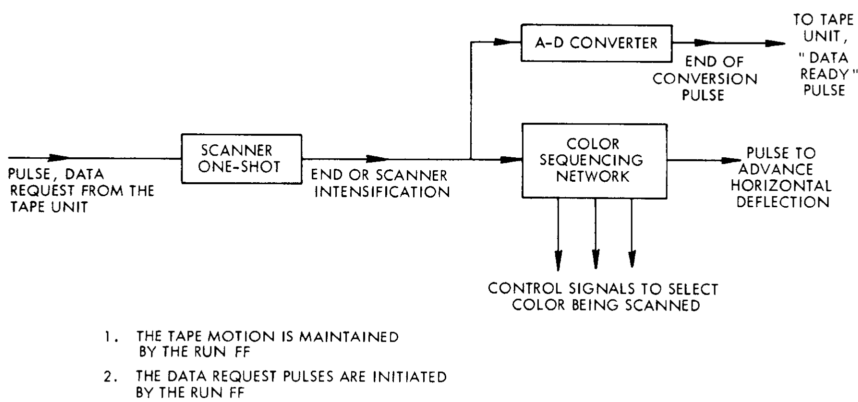

Fig. XIII-13. Record-mode symbolic timing chart.

After a point has been interrogated and the brightness digitized, the SCAD replies with a "data ready" pulse. This pulse has to be within a certain time range after the Data Request.

The data on tape are blocked into records. The locations of the end of record gaps are determined by the SCAD: the tape recorder will insert a record gap whenever the SCAD sends it a Write EOR pulse. These pulses may be sent after every four, two or one scanning line. The number of lines per record is selected by a switch on the control panel.

The tape unit plays back the recorded data while it is recording, and these data are displayed. There is some delay between the recorded data and the time they are played back, so that the picture one sees on the monitor while the equipment is recording is not a faithful replica of the signal actually on tape, but is useful primarily for monitoring the data.

e. Playback Mode

In the Playback Mode, the digital data from the tape unit are accepted by SCAD, converted to analog, and exhibited on both the Display and the Monitor. The timing chart for this operation is given in Fig. XIII-14 (the vertical advance and horizontal reset in the playback mode through the counters).

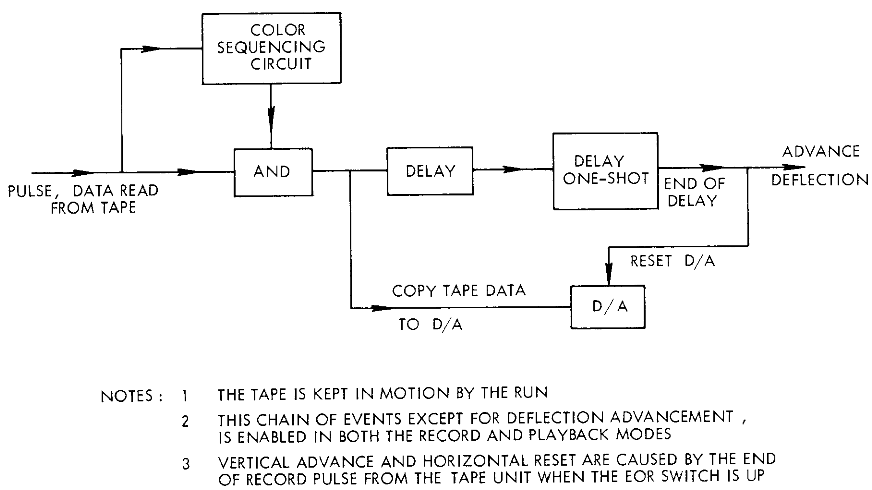

Fig. XIII-14. Playback symbolic timing chart.

The tape playback equipment detects the end of a tape record, and sends SCAD a pulse at this time. This pulse may be used as an alternate vertical advance and horizontal reset. The gate that permits this pulse to enter the counters is controlled by the Record Reset toggle on the front panel.

f. Color Operation

SCAD is capable of scanning and producing color pictures. The color signals are derived by splitting the light that passed through the transparency into three spectral bands, and measuring the amount of light in each band with a different PMT. Color pictures are obtained from the Display by photographing three separation pictures through three different color filters.

In the DF and DS modes, the color PMT that the equipment uses to obtain video is determined by switch setting on the control panel. In the record mode, the front-panel controls enable one to record any combination of the three color signals available; that is, one can record a monochrome recoding from each of the three PMT, or one of the three possible two-color pictures, or a three-color picture. When a multicolor picture is recorded on tape, the numbers for the three chrominance components of each scanning point follow each other on the magnetic tape, i.e. , the three color signals are interleaved.

When this sort of polychrome tape is played back, the color signals alternate. To obtain a photograph from this, the equipment selects and displays the signal corresponding to only one color component. The controls for selecting the required signal are on the control panel.

g. Computer Operation

When the SCAD is operated in the Computer mode, it can be regarded as an input-output device for the computer. SCAD accepts three commands: DEFLECT, INTENSIFY, DISPLAY.

In the DEFLECT command, the SCAD accepts 18 bits from the computer, copies the more significant 9 into the vertical deflection register, and the less significant bits into the horizontal register. The INTENSIFY command is used to interrogate the scanner, and the DISPLAY command is used to present data on the Display unit and the Monitor. When an INTENSIFY command is given, SCAD intensifies the scanner at the current location, converts the brightness to digital, and sends these digital data to the computer. It next takes 4 bits from the computer, sets these into the deflection direction control register, and increments both the horizontal and vertical counters. Appropriate bits in this register enable the computer to step the deflection to any of the 8 adjacent points. The logic on the deflection direction control is interlocked so that the deflection cannot be made to stand in one point. The size of the increment made by the deflection is controlled by the count entry switches. The color that is sent to the computer is controlled by two bits that the SCAD obtains from the computer.

When SCAD receives a DISPLAY command, it takes eight bits from the computer, converts these to analog, and displays a spot of this brightness at the current coordinates. The deflection is stepped after the display in the same way as in the INTENSIFY command.

O. J. Tretiak

2. PICTURE TRANSMISSION BY PCM OVER A NOISY CHANNEL

In a previous report[1] a graphical method for minimizing the mean-square error when PCM is transmitted over a noisy channel was described, and the effect of using weighted PCM for transmitting pictures was shown. The improvement in subjective picture quality when weighted PCM is used is due to the fact that a large number of small errors in intensity is less disturbing to the viewer than a relatively small number of large errors.

Since that time, an investigation[2] was made of how minimizing another quantity than the mean-square error affects the quality of the received pictures, and simulations were carried out whereby the quantity $|\epsilon^w|$, with $w = 1.5$ and $w = 3$, was minimized. The results showed that the quality of the received pictures varies only slightly with the weighting power w, with an optimum value of $w = 2$ when the channel has initially an error probability of .001 and .005, and $w \approx 2.5$ if the initial error probability is .01.

A scheme, in which only the 5 most significant bits of the 6-bit pulse group were transmitted and the receiver made a guess on the least significant bit, was also tried. The quality of the pictures after transmission over the noisy channels was comparable to that of 5-bit originals. When only 4 bits were transmitted, however, and a guess was made on the two least significant bits, there were noticeable contours in the received pictures.

Some experiments in which unequal steps were used in quantizing the intensity of the picture points were also performed. If the quantization is done well, the same picture quality can be achieved by using only 5 bits instead of 6. The intervals were assigned numbers 0 to 31; these were transmitted over the channel, and the receiver determined the corresponding intensity from the received number. Because of the nonlinear mapping of the interval numbers into the intensity levels, the minimizing procedure used with the equally quantized pictures could not be applied to the intensity directly, but rather was applied to the numbers assigned to the intervals. Simulations were carried out by using weighting powers $w = 2$ and $w = 3$, and the picture quality was again increased considerably when weighted PCM was used.

Very noisy PCM channels, as assumed in this work, do not occur frequently in practice. An example is shown of how such a channel could arise when the rate is increased while transmitting over a bandlimited channel, thereby introducing errors because of intersymbol interference. Another simulation shows how weighted PCM improves the quality of the pictures when transmitted over such a channel.

This report is a summary of a Master's thesis carried out under the supervision of Professor T. S. Huang; the author wishes to acknowledge his guidance and many helpful suggestions throughout the work.

H. P. Hartmann

References

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2. H. P. Hartmann, "Picture Transmission by PCM over a Noisy Channel," S. M. Thesis Department of Electrical Engineering, M. I. T., August 1966.

3. DIFFERENTIAL PCM

Differential PCM is a digital communication system that transmits a quantized representation of the difference between a signal sample and its predicted value.[1-4] This system is shown in Fig. XIII-15. The input, s(t), is a discrete-time signal formed from samples of a bandlimited information signal (t may be regarded as an integer index). The quantizer is viewed as a device that adds noise n(t) to the quantizer input, d(t). The predicted value of s(t), r(t), is formed by adding x(t−1) to the sum of all previous x. It should be noted that r(t) is also the system output and is formed at the receiving end in an identical manner. The following relations may be formed[5,6]:

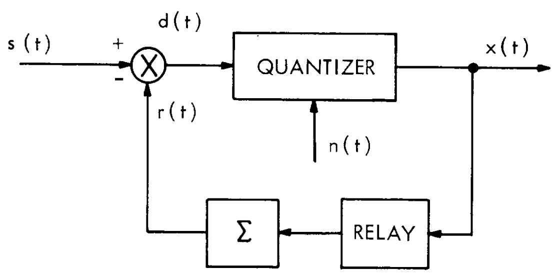

Fig. XIII-15. Differential PCM system.

$$r(t) = s(t-1) + n(t-1) \tag{1}$$

$$d(t) = \delta s(t) - n(t-1) \tag{2}$$

$$x(t) = \delta s(t) + \delta n(t), \tag{3}$$

where

$$\delta s(t) = s(t) - s(t-1)$$

$$\delta n(t) = n(t) - n(t-1).$$

Thus r(t) is the signal delayed by one unit plus the quantizing noise made the last time. The quantizer input, d(t), is the first difference of the information signal minus the delayed quantizing noise. The transmitted signal is the sum of the first differences of the information signal and the noise signal.

The noise power in a differential PCM system may be approximated by

$$\overline{n^2(t)} = \sum_{k=0}^{N-1} \int_{x_k}^{x_{k+1}} [y_k - z]^2 \, P_\delta(z) \, dz, \tag{4}$$

where x_k and y_k are the k^{th} decision and representation levels of the quantizer, $P_\delta(z)$ is the amplitude probability density of the first difference of the information signal, and N is the number of quantizing levels. Minimizing the noise power with respect to x_i and y_i leads to the following conditions on the differential PCM quantizer[7,8]:

$$x_i = \frac{y_i + y_{i-1}}{2} \tag{5}$$

$$\int_{x_i}^{x_{i+1}} [y_i - z]\, P_\delta(z)\, dz = 0. \tag{6}$$

The noise power in a standard PCM system of N quantizing levels is given by

$$\overline{n_p^2(t)} = \sum_{k=0}^{N-1} \int_{x_k}^{x_{k+1}} [y_k - z]^2\, P_\gamma(z)\, dz, \tag{7}$$

where $P_\gamma(z)$ is the amplitude probability density function of the information signal. It can be seen, by comparing of Eqs. 4 and 7, that if $P_\delta(z)$ is more peaked than $P_\gamma(z)$, the quantizer for a differential PCM system may be designed to yield a lower noise power than that for a standard PCM system. $P_\delta(z)$, in general, will be more peaked than $P_\gamma(z)$ for signals that are changing slowly with respect to the sampling frequency (i. e., highly correlated signals with downward sloping spectra).

The improvement ratio of a differential PCM system over a standard PCM system is given by $\overline{n_p^2(t)} / \overline{n^2(t)}$. This ratio can be evaluated on a digital computer by using Eqs. 4 and 7. These equations can be used for an arbitrary set of quantizers.

Another comparison of differential PCM and standard PCM is provided[5,6] by

$$S/N = \frac{1}{2[1-R]} [K\, S/N_p - 1], \tag{8}$$

where

S/N = signal-to-noise ratio of a differential PCM system

S/N_p = signal-to-noise ratio of a standard PCM system

K = the ratio of the differential PCM quantizer signal-to-noise ratio $\left[\overline{d^2(t)} / \overline{n^2(t)}\right]$ over the standard PCM signal-to-noise ratio

R = the first displacement of the signal autocorrelation function divided by the signal power $\left[\overline{s(t)\, s(t-1)} / \overline{s^2(t)}\right]$.

Equation 8 illustrates the fact that the improvement of differential PCM over standard PCM is dependent on the degree of correlation of the input signal.

The transmitted signal of a differential PCM system is given by Eq. 3. When the sampling frequency is considered to be 1 sample/second, the power density spectrum of x(t), $G_x(\omega)$, is given by

$$G_x(\omega) = [G_s(\omega)+G_n(\omega)]\, T(\omega),$$

where $G_s(\omega)$ is the power density spectrum of s(t), and $G_n(\omega)$ is the power density spectrum of n(t). (It is assumed that s(t) and n(t) are uncorrelated.) $T(\omega)$ is defined as

$$T(\omega) = 2[1-\cos\omega].$$

$T(\omega)$ is a sinusoid with a maximum value at one-half the sampling frequency, and thus tends to weight high frequencies much greater than low ones. If $G_s(\omega)$ is downward-sloping and $G_n(\omega)$ is flat (a characteristic of white noise), then the possibility exists that the noise power in a differential PCM system may be reduced at the receiving end by passing s(t) through a linear filter that attenuates the higher frequencies.

A simulation of both differential PCM and standard PCM systems of 8, 16, and 32 quantizing levels was made on the I. B. M. 7094 digital computer located at the Computation Center, M. I. T. The input consisted of 256 samples of one scanning line of a photographic transparency. Optimum quantizers were approximated graphically by using Eqs. 5 and 6. Because of the small number of sample points used, the input signal lacked smooth statistical properties; however, the signal did exhibit the downward-sloping spectrum desirable for differential PCM. The power of the signal was 1.65×10^{-2} volt,^{2} and the correlation ratio was 0.921.

Table XIII-3 provides a brief summary of the results of this simulation.

Table XIII-3. Comparison of differential PCM and standard PCM.

Quantizer Levels	PCM	Differential PCM			
	S/N_p	S/N_1	S/N_2	S/N_3	IR
8	56.2	80.8	101.0	87.8	1.44
16	244.0	520.	497.	523.	2.13
32	1553	2460	3560	2570	1.58

S/N_p and S/N_1 are the experimentally determined signal-to-noise ratios of the standard PCM and differential PCM systems, respectively. S/N_2 is the signal-to-noise ratio of the differential PCM system calculated by using Eq. 4. S/N_3 is the differential PCM signal-to-noise ratio calculated from Eq. 8, with the constant K experimentally determined. IR indicates the improvement ratio of differential PCM over standard PCM based on experimentally determined noise powers.

It can be seen by comparison of S/N_p with S/N_1 that the differential PCM system yielded significant improvement over standard PCM for all cases. The improvement ratio was maximum at 16 levels, and decreased considerably at both 8 and 32 levels. Since there is some question about whether the quantizers that were used were truly optimum, these results should not be used to form any conclusions concerning the relationship between the number of quantizing levels and the improvement shown by differential PCM.

Equation 4 proved to be an accurate means of estimating differential PCM signal-to-noise ratio, with one major exception occurring at 32 levels. This happened because representation levels of the quantizer were situated at small isolated areas of the probability density $P_{\delta}(z)$. When this happened, no error power was contributed by Eq. 4 within this interval. Error will always be present in such an interval, however, since Eq. 2 states that the input to the quantizer never exactly equals the first difference signal.

Except for 8-level standard PCM, the noise in all systems was characteristically white (impulselike autocorrelation function and flat power density spectrum). The spectrum of the 8-level standard PCM system noise exhibited a downward-sloping spectrum similar to that of the input signal. A result like this is to be expected for coarsely quantized signals.

Finally, the improvement of differential PCM over standard PCM for this simulation cannot be considered to constitute a bandwidth reduction of one bit. This comparison should not obscure, however, the possibility of much greater bandwidth reduction resulting from the inherent subjective superiority of differential PCM as demonstrated for video signals.[2]

J. A. Newell

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4. VARIABLE-VELOCITY DELTA MODULATION

Delta modulation[1] in its simplest form is shown in Fig. XIII-16. Incoming data are compared with the value in an accumulator (integrator), and a fixed-quantity "delta" is

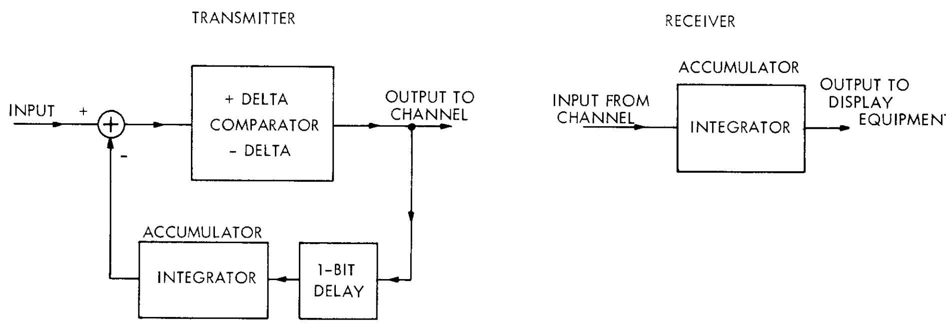


Fig. XIII-16. Simple delta modulation.

added to (or subtracted from) the accumulator so that it follows the input data. The output of the delta-mod transmitter is a string of bits that give the polarity information of each delta. At the receiver, the bits are decoded and added (or subtracted) to a similar accumulator whose value is the system output.

The cameraman picture original (Fig. XIII-17a) has been transmitted by a single-bit delta scheme, and the result is shown in Fig. XIII-17b. (All results shown were obtained by computer simulation.) Figure XIII-17b blurred because a too small delta was used. That is, the accumulator could not change to required brightness levels within a sufficiently few picture points. Figure XIII-17c shows the result of using a large delta. In this case the contours are sharp, but the range of different possible brightness is too restricted.

One popular solution to the problem of having too large or too small deltas is the use of two different sized deltas instead of only one.[2] Figure XIII-17d is an example of such a scheme, and the picture looks quite good; however, there has been a doubling of the transmitted information. In general, N bits/picture point will allow 2^{N-1} different sized deltas.

A new digital picture coding scheme has been invented which in some respects is similar to variable-velocity scanning[3] in analog T.V. systems. It has been named variable-velocity delta modulation[4] because the scan rate in the system is not constant. In all other delta-mod systems, the scan moves to the next picture point independently of whether or not the accumulator has changed enough to be a good approximation to the input data. This is the reason for the blurred contours of Fig. XIII-17b. The variable-velocity delta-mod transmitter keeps adding (or subtracting) deltas to the accumulator

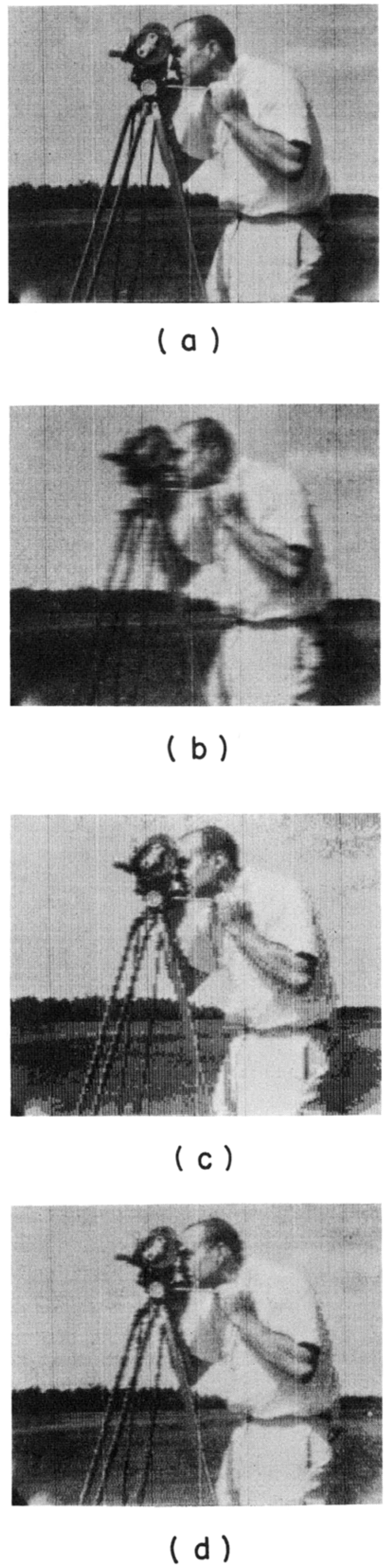


Fig. XIII-17. Ordinary delta modulation.

until the input data value is equaled or the difference is within one delta, and only then does the scan move to the next picture point. A reversed polarity punctuation bit is added

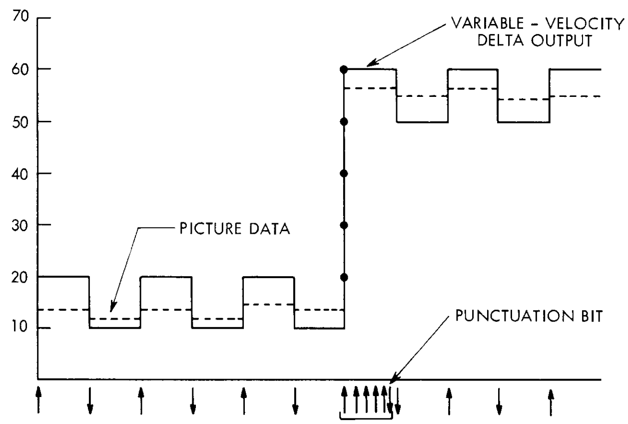


Fig. XIII-18. Variable-velocity delta modulation.

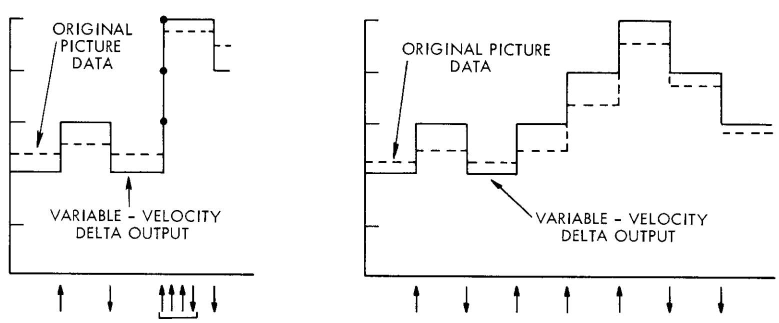


Fig. XIII-19. Example of ambiguous message sequence.

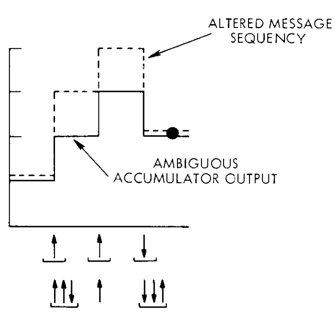
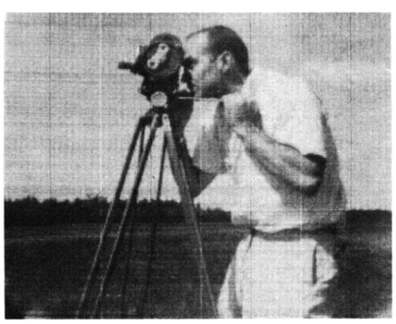


Fig. XIII-20. Example of altering scheme.

to the end of strings of two or more identical polarity bits in order to help the receiver detect multi-delta picture points (see Fig. XIII-18). Note that when a picture has large regions of relatively constant brightness, adjacent picture-point differences will most likely be within one delta, and therefore only one bit/picture point need be transmitted. The scheme is adaptive, since the number of bits/picture point is determined by the current needs, and therefore varies throughout the picture.

The receiver is designed to search for strings of identical polarity bits followed by a reversed polarity punctuation bit. For example, the five-in-a-row positive bits in Fig. XIII-18 are decoded as five deltas to be added to the receiver accumulator. It is possible for identical bit sequences to be transmitted from entirely different inputs (see Fig. XIII-19). To prevent such ambiguous sequences, it is necessary to test the bits to be transmitted for one of seven possible ambiguous cases. If one is found, then the message must be altered slightly so that the receiver will not make serious errors. The altering scheme introduces small errors, but they are hardly visible. One of the seven cases is shown in Fig. XIII-20. The top string of arrows represents the ambiguous message. Observe that the receiver would lump the first three bits together into the data

(a)



(b)

Fig. XIII-21. Variable-velocity delta modulation.

for a single picture point. The lower string of arrows, however, represents the bits that are actually transmitted, and the dotted line is what is seen at the receiver. The remaining six ambiguous cases are given in the author's thesis.[4]

The cameraman, transmitted by variable-velocity delta-mod with a small delta used, is shown in Fig. XIII-21a. The over-all average for the picture is 2.5 bits/picture point. When a larger delta is used, as shown in Fig. XIII-21b, the average drops to 1.75 bits/picture point. Note how much sharper the contours appear with variable-velocity delta-mod than with 2-bit delta-mod (i.e., 2 bits/picture point) as in Fig. XIII-17d.

S. D. Shoap

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B. SENSORY AIDS

1. WORD-AT-A-TIME TACTILE DISPLAY

A device has been constructed, and partially evaluated, which permits the simultaneous presentation of a maximum of 8 Braille-like cells to the fingers of both hands. An individual Braille cell is presented to each finger according to the stimulus locations shown in Fig. XIII-22. Here a character is very similar to the standard Braille character. Dots 1 and 4 stimulate the finger on the uppermost bone, dots 2 and 5 on the middle bone, and dots 3 and 6 on the lowermost bone next to the palm. With the hand placed palm down, dots 1, 2, and 3 stimulate the left side of the finger, while dots 4, 5, and 6 stimulate the right side.

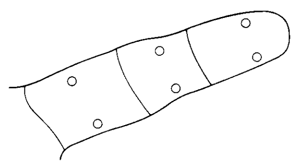

Fig. XIII-22. Stimulus locations.

As an individual Braille character requires only one finger, it is possible to present as many as 8 characters simultaneously (use of thumbs has been excluded for convenience). Therefore, words of 8 or less letters can be presented to the blind reader.

a. Description of the System

The system is capable of displaying blocks of information originating from punched paper tape, through tactile stimulation of the fingers, to a person at a rate that is variable from one block per 10 seconds to two blocks per second. Each block of information may consist of any amount of information from a single dot on a single finger to 6 dots on each of 8 fingers simultaneously.

A block diagram of the system is shown in Fig. XIII-23. The block paper tape reader is capable of reading 12 rows of information from an eight-column tape, or 96 bits of information, on each cycle. The information is precoded onto punched paper tape by a PDP-1 computer program. The block paper tape reader is driven remotely by a variable-speed pulse drive which is controlled by the experimenter. The information control gates information to the solenoid drivers. Solenoids are used to provide the stimulus which is supplied to the fingers. The lamp display serves to

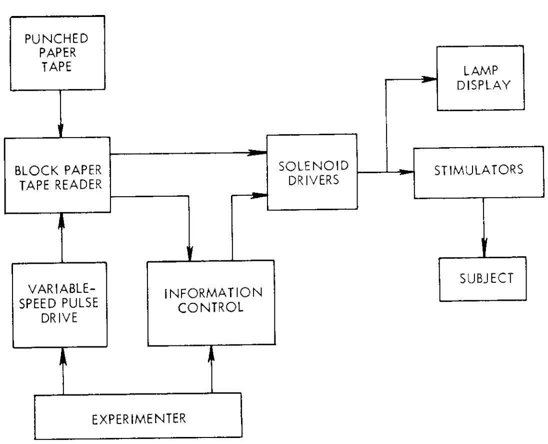

Fig. XIII-23. The system.

moniter, for the experimenter, the drives applied to the solenoids in the stimulators.

b. Experiments and Conclusions

The objects of the experiments were, first, to determine whether or not Braille readers would be able to transfer their knowledge of Braille to the use of this system and hence be able to recognize individual stimulus patterns as letters and, second, to determine the reaction of the blind person to the system, by soliciting his opinions, criticisms, and suggestions for modification of the system.

Initially, each subject was familiarized with the system. The over-all operation was explained. The locations of the stimuli were indicated and the correspondence of the stimulus patterns on the finger to the Braille cell was emphasized.

Early experiments were designed to fix stimulus patterns with groups of letters in the subject's mind. The subject was presented multiple-letter patterns on his left hand, informed of their identity, and asked to verify them. Because of lack of time and slowness in progress, only the left hand was used.

In later experiments a pattern was presented and the subject asked to identify it, being corrected, if necessary, immediately afterward. This was done with single-letter patterns, two-letter patterns, and common three-letter words.

The test described here consisted of a random finger test, summarized in Figs. XIII-24 and XIII-25. The purpose of this test was to determine the relative ability

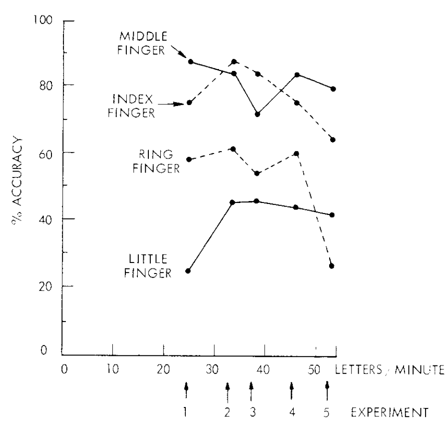

Fig. XIII-24. Random finger test. Each point represents an average of 25 data. (Subject: S_1.)

of each of the fingers to recognize single characters. For each experiment in this test 100 letters were presented, one at a time, in random fashion, so that each finger had exactly 25 letters presented to it. At any given time during an experiment only one finger had a letter presented to it. These experiments were performed for each of the letter rates given below. In each experiment the same letters were used but in different order.

1. 25 letters per minute
2. 33 letters per minute
3. 38 letters per minute
4. 46 letters per minute
5. 53 letters per minute.

(The fifth experiment was not performed on subject S_2.) The results of this test support the previous belief that the little finger is least able to perceive the stimulus. There are insufficient data here to determine which finger, if any, is best able to perceive stimulus. The weakness of the little finger gives a hint, however, that when a word is to be presented to both hands jointly, it may be advantageous to center the word about the two index fingers when it requires less than all 8 fingers.

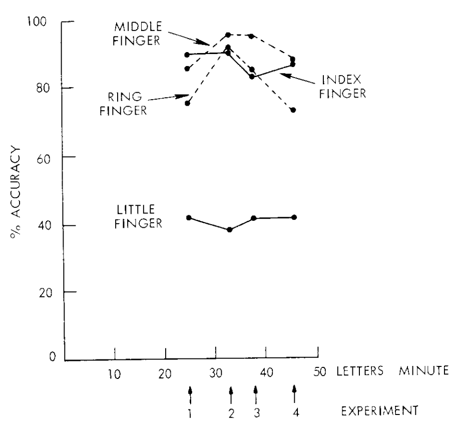

Fig. XIII-25. Random finger test. Each point represents an average of 25 data. (Subject: S_2.)

A more complete description of the other tests, as well as the opinions and suggestions of the subjects, may be found in the author's thesis.[1]

In conclusion, it appears to be correct to say that there is considerable transfer of knowledge of the Braille code, as normally read, by the subjects to the recognition of individual patterns as displayed by this system. Certainly, more extensive tests are required before a complete evaluation of this system can be made.

J. A. Williams

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2. METHOD FOR STORAGE OF BRAILLE

Research is under way at the Massachusetts Institute of Technology, and elsewhere, on machines to identify (recognize) printed characters, independently of type size, style and font. Such machines, which are approaching practicability, are intended for use in reading machines for the blind. Most workers have attempted to provide an output to the blind user in the form of spelled speech or phoneme strings,[1,2] in spite of the fact that with present technology such a machine would be prohibitive in terms of size and price to a typical, prospective user.

While it is now possible to build a machine that will read print and produce it as Braille on-line, it will be some time before such a machine can be made portable, and in fact, it may never be economically feasible to do so. A centrally located reading machine providing embossed Braille books would not be satisfactory; Braille books are heavy and bulky, and as reading machines become widespread, and the amount of reading material available to blind people approaches that available to sighted people, blind people with only moderately sized libraries will encounter severe storage problems.

As a solution to this problem, this report suggests that the output of the reading machine be in the form of magnetic tape, which, in turn, is converted to Braille. The approach is intended for use with a central facility for translating printed material to tape. The user would store the tape, convert it to Braille as needed on a portable unit, and destroy the Braille after use. A scheme has been developed with the following provisions:

1. compactness of storage on tape comparable to that of print, in terms of size and weight;
2. conversion from magnetic tape to Braille on inexpensive, portable equipment;
3. conversion from magnetic tape to Braille at continuously variable word rates, ecompassing all speeds at which Braille is read; and
4. an error check, and reasonably low error rates.

The magnetic tape record/playback unit was designed for use with braillers that require input information at the word speed at which the user chooses to read; accordingly, the magnetic tape unit must provide output at continuously variable word rates. Hence the tape must be either intermittently clutched or drawn steadily across the heads at continuously variable rates. It was considered impractical to build a portable unit that drives tape intermittently, and so the alternative, that of variable tape speeds, was selected.

Tape data systems almost always use saturation recording techniques and some form of frequency or phase modulation, because of amplitude variations in the so-called linear region of the tape.[3,4] The present requirement of continuously variable tape speeds rules out phase- and frequency-modulation systems because both would require critical settings of a playback oscillator or filter. Amplitude-modulation systems have the overwhelming advantage of being relatively insensitive to tape speed, since it is easy to compensate for the fact that over-all amplitudes vary linearly with tape speed. As for amplitude variations caused by tape imperfections, their effect can be reduced to a tolerable level by using simple redundancy. Since the final link in the system is to be a human possessed of considerable error-correcting ability, errors are not as undesirable as they would be, for example, in a data-processing system. It was estimated that one error per 100 or 200 characters would not be objectionable,[5] and this order of error rate was achieved with the amplitude-modulation scheme described here.

The AM technique has two further advantages, in that the scheme lends itself to realization with a minimum of hardware in the playback unit, and hence facilitates portability. To the same end, it developed that any small tape recorder that could handle speed intelligibly would suffice for recording and playing back Braille, when appropriately modified. The resulting tape unit is potentially portable and inexpensive.

A ternary, or three-level, code is employed, and all signals are recorded at a single frequency. (Effective frequency on playback varies with playback speed.) The three possible signals on the tape are a "high" bit, consisting of 8 cycles at a relatively high amplitude, a "low" bit, consisting of 8 cycles at some lower amplitude, and a "null" bit, consisting of 8 periods of zero amplitude. Each Braille cell is encoded in 9 bits: the first bit is always high, the next 6 bits are high or low, in such a way as to represent dots and their absences, respectively, in the Braille cell, the eighth bit makes the over-all parity odd, and the ninth bit is a null bit, used for synchronization.

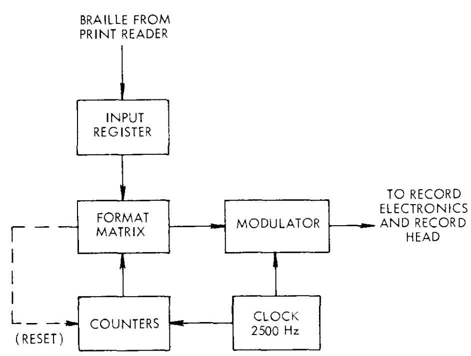

Fig. XIII-26. Record section.

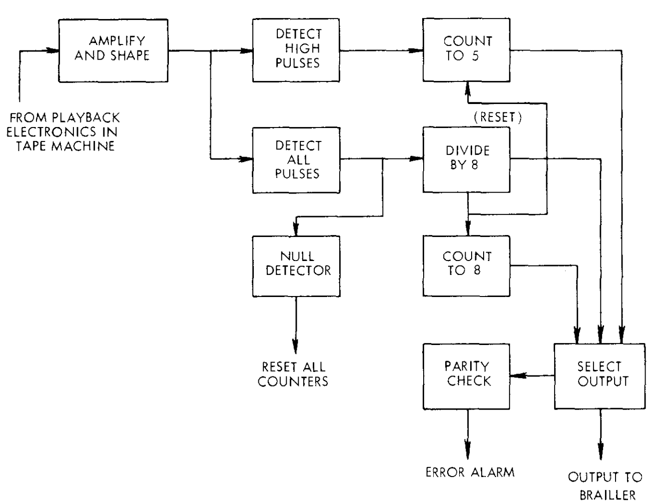

Fig. XIII-27. Playback section.

The record section is entirely straightforward, and can be seen in Fig. XIII-26. It serves to generate the format described above.

The playback section is somewhat more involved (Fig. XIII-27). Two separate counter chains are employed: one is reset by the null between characters and, by counting all cycles ("pulses"), keeps track of which bit in the Braille cell is under the playback head. The other counter registers only high-amplitude cycles, and so judges each bit to be high or low. If the majority of the 8 cycles in a bit is received as high, the bit is counted as high, otherwise, as low. This information is passed on to the brailler, together with an audible alarm that the playback parity is not odd.

It is clear that every cycle need not register perfectly in order that a character be correctly interpreted. For example, the first counter can gain or lose up to 4 cycles per character, and still cause perfect output. The second counter can wrongly judge (as high or low) up to 4 cycles per bit, and still produce perfect output. Furthermore, the use of the null bit between characters prevents the carrying over of wrong counts from one character to the next. The use of 8 cycles to encode each bit offers considerable protection against noise, while maintaining a reasonable words-per-reel density.

A prototype was constructed to test the feasibility of these ideas. Sample material was recorded at 7 1/2 inches per second, with a "carrier" frequency of 2500 Hz. This corresponds to 416 words per minute, which is faster than Braille reading rates. The system was intended to be continuously variable down to 0.18 inch per second, which gives a playback carrier frequency of 60 Hz and a bottom reading rate of 10 words per minute. With the encoding scheme described here, and 8 tracks consecutively of standard, 1-mil, one-quarter inch audio recording tape, one seven-inch reel stores 140,000 English words. This words-per-volume ratio is superior to that of hard-cover books, and is comparable to that of thin-paper paperback books. Experimental error rates were approximately one character in 200, better than current print readers by an approximate factor of twenty.

M. B. Lazarus

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