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An objective automated method for digitizing pictorial material for computer manipulation

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An inexpensive device to digitize existing pictorial material in conjunction with a digital computer is described. Slides (35-mm) are used as source material, and the slide is scanned to produce a two-level output (i.e., dot present or dot absent). The system has spatial resolution of approximately 1 mm and a complete scan (30 times 19 points) is completed in about 20 sec. Although we are using the system to produce only two level outputs, there is no reason a gray scale could not be constructed.

Laboratories that use computer generated and controlled displays for experimentation often find a need for the reverse process, i.e., digitizing of existing pictorial material for computer analysis and manipulation. Such a task might be performed for experiments on pattern perception, texture perception, or visual search. Devices which perform this function, flying spot scanners, have been used in television and in amateur radio communications for many years, (Fink & McKenzie, 1975; American Radio Relay League, Note 1). However, most such devices are complex and involve the use of high-voltage vacuum photomultipliers, may involve precisely aligned optics, and are generally designed as integral components of communications networks of greater or lesser complexity.

We have constructed a simple inexpensive flying spot scanner which digitizes pictorial material in conjunction with a digital computer. It does not involve high-voltage power supplies or optics and its output levels are compatible with manipulation by computer. The computer provides a raster to drive a point of light across an oscilloscope screen; a transparency of the material to be digitized is interposed between the oscilloscope screen and a photosensor with amplifier which provides an output voltage proportional to transmission of the slide at each raster point. These voltages are digitized and a matrix of values corresponding to slide transmission at each point is produced. We are using the device to provide only binary output but, in principle, there is no reason any number of levels of transmission should not be digitized.

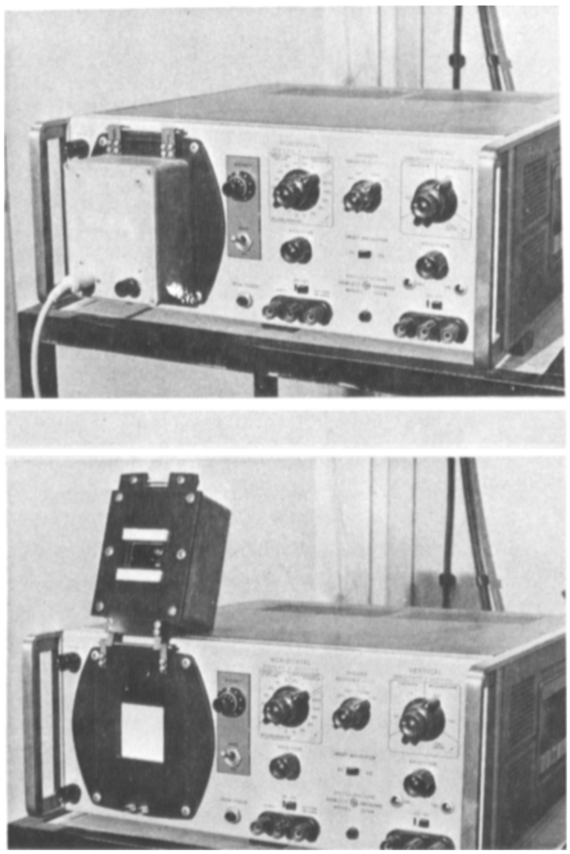

Figure 1. Hewlett-Packard oscilloscope with light-tight slide holder and box for photodetector and amplifier.

IMPLEMENTATION

Hardware and Software

The device was constructed so as to hold a 35-mm slide against the oscilloscope face (Figure 1); the photosensor and amplifier are housed in a light-tight box with a window to admit light transmitted through the slide. Figure 2 shows the photosensor/amplifier circuit. Tr 1 and Tr 2 form a Darlington pair, which provides much greater sensitivity than a single phototransistor. Inclusion of Tr 3, which is masked so as to admit no light, Tr 4, and R 2 at the noninverting input of IC 1 reduce the sensitivity of the circuit to changes in ambient temperature. The effectiveness of this procedure depends on the matching of Tr 1 to Tr 3, Tr 2 to Tr 4, and R 1 to R 2. RV 1 is a 10-turn potentiometer, made easily accessible (see Figure 1) to facilitate compensation

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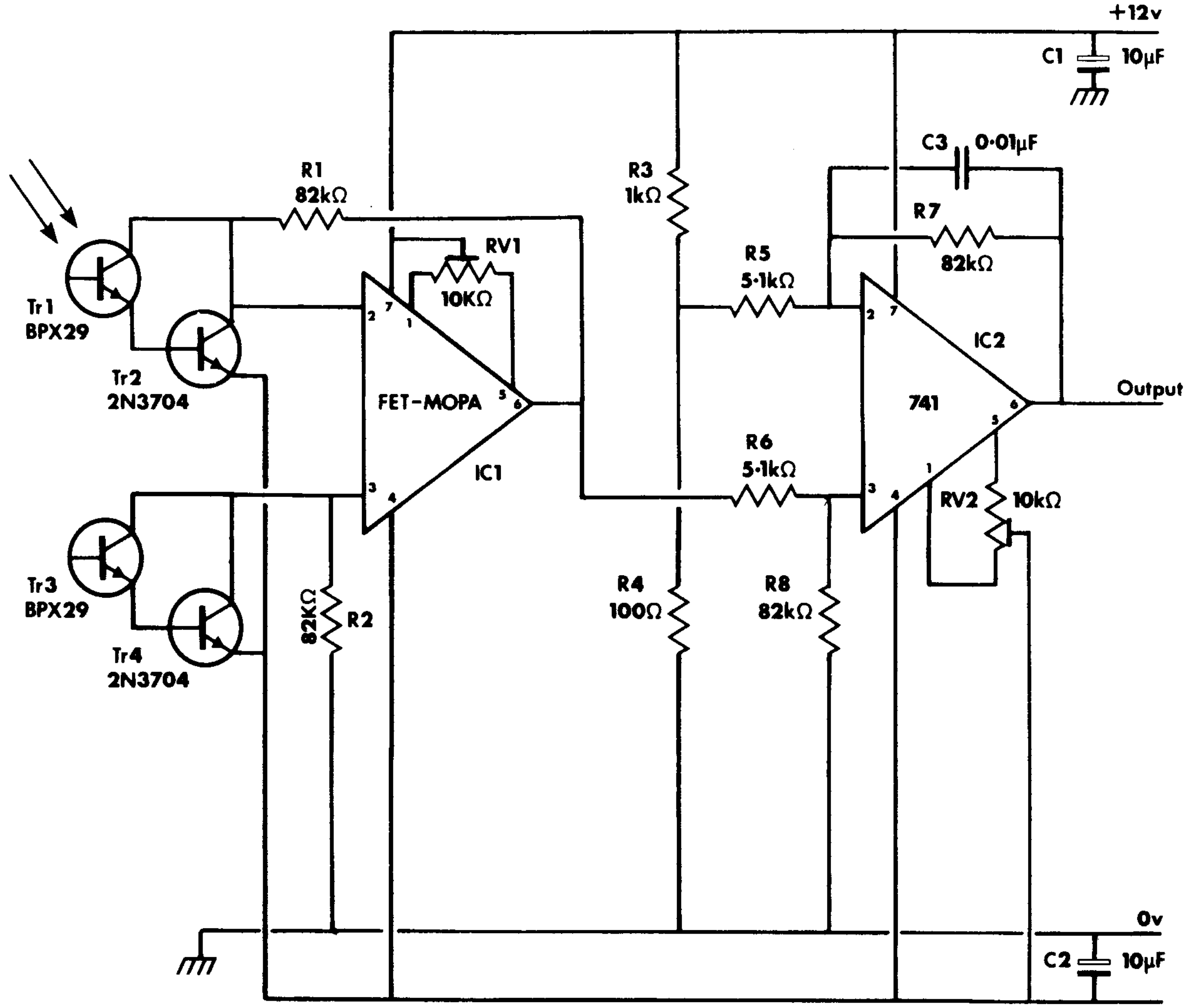

Figure 2. Detectors and amplification circuit (see text).

for changes in output voltage level due to changes in ambient temperature. The remainder of the circuit amplifies the output of IC 1 and sets the high-frequency cutoff of the system, by means of C 3 across the feedback resistor of IC 2, at 250 Hz (−3 dB). A parts list is provided in Table 1.

Three particular difficulties were encountered with the system, viz, matching the sensitivity of the photosensor to the light emitted from the oscilloscope, thermal drift in the photosensor circuit front end, and compensating for the variation in directional sensitivity of the photosensor. Silicon photosensitive devices in general have spectral sensitivity which peaks in the near infrared (approximately 900 nm); the P-31 phosphor of the Hewlett-Packard oscilloscope (Model 120 B) used emits light which peaks at 525 nm. Use of a cathode ray tube with an orange or red phosphor would increase sensitivity of the system but drastically reduce scan rate, since these phosphors have much longer persistence. The mismatch of the spectrum of the emitted radiation and sensor characteristics necessitated high gain in the amplifier circuit, thus thermal drift became a problem. It was minimized by use of a matched pair of front end components (see above) and the software was designed to check and compensate for any remaining drift. Over the time taken for a scan of the slide (about 20 sec), this was negligible compared to the voltage change corresponding to the maximum difference in brightness levels (see Figure 4). Variations in directional sensitivity of the photosensor can be compensated by the software if a "blank scan" is carried out with a blank slide in place. The value obtained at any point with the experi-

Table 1
Parts List*

1	FET operational amplifier (US equivalent Analog Devices AD 0042 C.)	$ 5.80
1	741 operational amplifier	1.00
2	BPX 29 phototransistors (Mullard or Phillips)	6.00
2	2N 3704 transistors	2.00
8	½-W resistors (4 × 82 kΩ, 1 × 1kΩ, 1 × 100Ω)	1.00
1	10-turn 10-kΩ potentiometer	5.00
1	10-kΩ trimpot	1.00
3	capacitors (1 × .01 μF, 2 × 10 μF)	2.00
	Box, hardware, circuit board, plugs, knobs, etc.	15.00
		$38.80

**Power supplies externally supplied from computer.*

mental slide is then expressed as a proportion of that obtained at the same point with the blank slide.

For most systems with small computers, digitizing even a 35-mm slide with oscilloscope spots of practical sizes (down to about .5-mm diam) will result in a surfeit of data. We have accordingly designed the software to operate in two modes. In the first mode, single points are measured within areas of specifiable size and the output value of the device is taken to represent transmission within that area. The size of this area in part determines the resolution obtained; it is maximal when the specified area is one unit, and falls off as fewer points are measured within the specified area. In the second mode, the spot is moved to all possible points within the specified area and the output values averaged to give the value representing transmission within the area. This second mode is less likely to completely miss small high- or low-contrast areas but is much more time consuming.

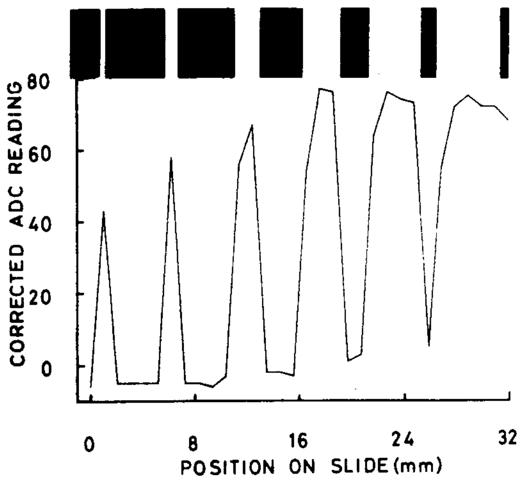

Figure 4. Analogue-to-digital converter output (corrected for thermal drift) as a function of position across a slide with a luminance distribution shown at the top of the figure.

VALIDATION

Relation Between Light Input and Output Voltage

This relationship is primarily determined by the characteristics of the sensor. Figure 3 shows output voltage as a function of light input for the device. Output from the system is approximately linear over a range of about 1 log unit. A straight line fitted to the central five points of Figure 3 (using least squares criterion) accounts for 91.9% of the variance in that region. It should be remembered that in using photographic material there will inevitably be reduction in luminous contrast because of the nature of the photographic process itself. Some further contrast losses are inevitable in a system such as this.

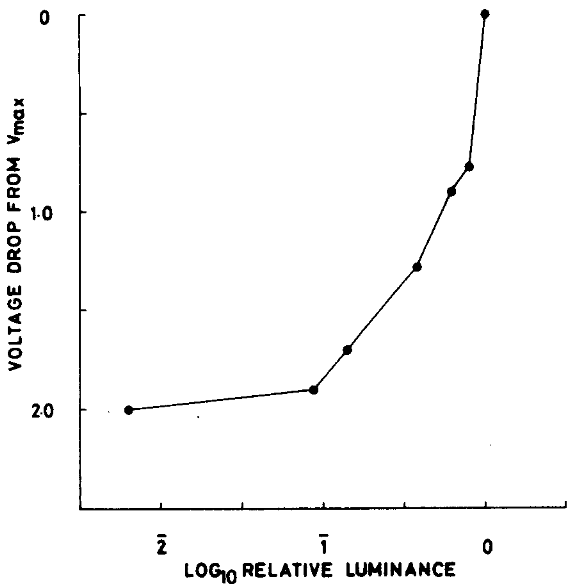

Figure 3. Output voltage change as a function of luminance of test spot seen by photosensor.

Spatial Resolution

Figure 4 shows the spatial resolution characteristics of the device. Analogue-to-digital converter output is shown as a function of position on a slide with the luminance distribution as shown. The device will resolve detail of approximately 1 mm when operated so that it scans one point in each 1.25-mm square of the slide area. (With our system, the maximum possible number of points in this area is four.) This mode of operation seems to be the best compromise to allow fairly fast scan times, to minimize drift problems, and to provide an adequate amount of data and resolution. Of course, these factors would need to be assessed in the light of each particular application.

Because the oscilloscope spot is displaced behind the slide by the thickness of the oscilloscope face, there is some parallax error introduced in the digitized material. This could be corrected by program modifications, but in our experience the distortion is small. Assuming a screen thickness of 6 mm, the maximum parallax error introduced is 1.7 mm at the edges of the slide. This will decrease as the tangent of the angle between detector axis and position on the slide.

Figure 5. Digitized output (below) of the photograph at the top of the figure.

Selection of Criterion

Criterion is defined as the cutoff analogue-to-digital converter value, above which the digitized matrix will be assigned a one and below which the matrix will be assigned a zero. Criterion selection is inevitably subjective in nature and intuitively one would select the mean or median value of corrected luminance to give a good approximation to slide detail. The concept of a good approximation involves subjective assessment of the pictorial material and its digitized equivalent. The median is probably a better measure to use than the mean, since it is not disturbed by extreme values.

Very high or very low criterion values results in output matrices in which the number of transitions of state (i.e., from one to zero or vice versa) is very low. Criterion could arbitrarily be set at that value which gives the maximum number of transitions. Figure 5 shows an example of the device output. In this case, the median criterion and the criterion of the maximum number of transitions produced the same output matrix.

REFERENCE NOTE

1. *Specialized communications techniques for the radio amateur.* Newington, Conn: American Radio Relay League, 1975.

REFERENCE

Fink, D. G., & McKenzie, A. A. *Electronics engineers handbook.* New York: McGraw-Hill, 1975.

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