INSTRUMENTATION & TECHNIQUES

The television camera used to measure movement

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A method is described in which the signals from a vidicon television camera are converted into vertical and horizontal voltage coordinates to reference the position of a moving target. Although limited in frequency response, the device is capable of measuring various types of movement activity.

Detailed measurement of the position of an animal or its limbs as a function of time is of value in correlating central neural activity to behavior (Fox & Rudell, 1968; Rosenfeld & Fox, 1972). This note describes a method for measuring behavioral movement that requires the attachment of no, or minimal, apparatus and produces a voltage output that is a function of the position of the object in space.

TECHNICAL DESCRIPTION

The input of the system is a vidicon television camera. The television camera generates a video signal, which is an analog voltage corresponding to the intensity of illumination at a set of points within the video field. This is accomplished by scanning a photosensitive surface with an electron beam in a raster pattern. American television utilizes a standard frame format that is composed of 525 horizontal lines. The frames are repeated 30 times/sec. Each frame is composed of two sequential interleaved rasters of 262½ lines, so that the entire video field is scanned at a rate of 60 Hz (Eastman, 1969).

Because the video field is scanned in a uniform and sequential fashion, the time at which an event is detected in the video signal, relative to a synchronizing pulse, provides information about the spatial position of the object that produced that event. For measurement purposes, the passage of time can be represented by a linearly increasing voltage function, as the sawtooth waveform. A sawtooth waveform synchronized and repeated once for each raster provides an accurate estimate of the position of the electron beam in the horizontal dimension. Similarly, a sawtooth synchronized with the horizontal line gives the position of the beam in the horizontal dimension.

With the video scene arranged so that a single bright

spot appears as a target on a dark background, a pulse is produced in the video signal when the scanning electron beam of the vidicon camera crosses the illuminated area. This pulse, or change in voltage, can be detected and used to extract spatial information from the vertical and horizontal sawtooth waveforms.

The block diagram in Figure 1 shows the manner in which the various elements of the system are interconnected. The video signal, probably with some amplification, is gated into a comparator together with a reference voltage. The gating signal is produced by two one-shots synchronized with the field sync pulse. Their durations are adjusted so that the video signal is not passed during the blanking period. This gate suppresses an artifact that may appear in the video signal at the onset or offset of a raster.

When the beam is in a dark region, the video out-

Figure 1. Block diagram of one method for converting television camera signals into voltage values that describe the position of a spot in the vertical dimension (VER OUT) and the horizontal dimension (HOR OUT). When the electron beam is turned on or off, an artifact may appear in the video signal. To prevent it from falsely triggering the acquire one-shot, the field sync pulse triggers a one-shot series to form a window. The window is adjusted to pass the video only after the onset artifact and before the offset artifact.

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put remains below the reference voltage and the comparator is in its lower state. When the beam enters an illuminated zone, the video signal increases to a value greater than the reference voltage. The comparator changes state and triggers a one-shot. The output of this one-shot briefly sets the two sample-and-hold circuits to the acquire mode, enabling their output to reach the voltage levels present in the sawtooth waveforms.

The acquisition time can be made small (a few hundred microseconds) enabling the sample-and-hold circuits to operate primarily in the hold mode. The held voltage represents the time, and therefore also the position, at which the last point was detected. If the spot subtends five horizontal lines, the output is held constant for more than 99% of the time. The high-frequency aspects of the output signal, dependent on the contour of the object and the movement of the object from one frame to the next, can be removed by low-pass filtering. This necessarily occurs in a display device with limited-frequency response, such as a polygraph, or an ink writer. In this case the estimate of the object's position is based primarily on the point last detected in a raster.

The functional diagram shown in Figure 1 can be implemented in a variety of ways. In one frequently used system, an oscilloscope (Tektronix 532, with Type d high-gain differential plug-in unit) is used to amplify and display the video signal produced by a Sony 3400 vidicon television camera. The vertical output of the oscilloscope drives the logic circuitry. In this way the gain and the baseline of the video signal can be adjusted to suit a fixed reference level. The logical elements are monostable multivibrators with Schmitt-trigger inputs (Texas Instruments, SN74121) supplied with +5 V. The sample-and-hold circuits are produced by Datel System, Inc. (Model SHM-1c-1), and are powered by a positive and negative 15-V supply. The amplitudes of the sawtooth waveforms are adjusted to about ± 1 V in order to provide output values suitable for recording on frequency-modulated magnetic tape.

Other display devices, and especially the computer, can use features of the spot to give a more accurate estimate of its position. For example, the detection of a point can trigger an interrupt that enables the computer to digitize and store the set of numbers that describe the outline of the spot in addition to the position. The accuracy of the estimate of the center of the spot is improved by taking the mean of the set of numbers.

A computer system (Digital Equipment Corporation PDP 11/45) was used to determine how lag time and accuracy of spatial representation varied with the rate of movement.

To provide replicable patterns of movement, waveforms were applied to the vertical and horizontal axes of an oscilloscope upon whose screen the television camera was focused. These waveforms and the output

of the sample-and-hold circuits were digitized so that cross-correlation functions could be computed between input and output (see Figure 2, top).

For a 2-Hz triangular wave, the cross-correlation coefficient approached 1 (greater than .99), with a lag the order of 1 raster (1/60 sec). The most important reason for this delay is the time required for illumination to produce the peak resistive change in the photo-sensitive surface of the vidicon tube, and the time required for this change to decay when the illumination is removed. If the reference voltage is set to a value equal to 50% of the peak video value, the raster immediately following light onset will reach the trigger level; 1 raster after illumination offset, it will fall below

Figure 2. Results of testing the television camera coordinate encoder. The television camera was focused on the screen of an oscilloscope, which produced a spot of light at the position determined by voltage inputs to the vertical and horizontal axis. The time relationship for input and output was determined by driving both axes of the oscilloscope with triangular waveforms and computing the cross-correlation function between input and output, as shown at the top of the figure. Spatial aspects were tested by driving the oscilloscope with the tape recording of a computer-generated test pattern. The system tested differed from that shown in Figure 1 in that the vertical coordinate was determined by counting horizontal lines and a computer average of vertical and horizontal coordinates was used to determine the spot's position.

the trigger level. If the trigger level is set lower, to about 25% of the peak value, a given point retains a resistance change sufficiently large to reach trigger level for up to 4 or 5 rasters following illumination offset. This results in greater lag between input and output.

A low trigger level produces a smoothing effect by basing the estimate of the spot's position on the average of its position during a time period of several rasters. This integrative process also decreases the high-frequency response of the system. For a wide range of trigger levels, the output amplitude for triangular waves repeated at 2 Hz or less is more than 90% of the output amplitude observed for very slow frequencies. Above this rate the output amplitude declines with increasing frequency, but more rapidly for the lower trigger levels, such that at 30 Hz the output amplitude for a low trigger level could be less than 50%; for a high trigger level, the amplitude is more than 80%. Higher frequencies exceed the Nyquist rate for aliasing.

A test pattern used for checking linearity, symmetry, and quality is shown at the bottom of Figure 2. Each dot corresponds to a position determination computed for each raster. The rounded corners indicate limited high-frequency response. A degree of warping produced by nonlinearity in the sawtooth waveforms is also observable.

BIOLOGICAL APPLICATION AND DISCUSSION

The results indicate that a standard television camera can be used to measure the position of an object in space as a function of time. Although this effect can be achieved also by cinematographic methods, the television camera has the advantage of nearly immediate readout and display. In addition the data are in a form that can be easily entered into a computer to be used for correlative analysis with other simultaneously entered data, such as electromyographic activity or other physiological variables.

The major limitation of the television camera is its limited-frequency response, which precludes its use for very rapid movements. However, it is adequate to resolve many behavioral movements in experimental animals. For example, the system has been used successfully to track the movement of a cat's paw during certain behaviors, such as the contact placing response (Amassian & Rudell, 1978) or the withdrawal reflex.

Using appropriate computer algorithms, it is possible to track several spots simultaneously. This provides a greater amount of useful information. For example, by placing markers at four points on a cat's limb (shoulder, elbow, wrist, and digits), it is possible to record the

Figure 3. Computer plot of the trajectory of limb displacement of a kitten (11 days old) during the contact placing response. When the kitten was moved forward (left to right), the dorsal surface of the digits encountered an obstacle, evoking the complex limb movement that caused the stimulated paw to be lifted and placed on the surface of the obstacle.

trajectory of the entire limb, including the sequence of angle changes that occur for different types of responses (see Figure 3). The markers are small circles of paper coated with a material that fluoresces in the green region when stimulated with ultraviolet light. A green filter placed over the camera lens blocks the entry of most of the background white light that reflects from the cat's fur. A green light-emitting diode also provides a good marker, but requires the attachment of cables or a small battery. Most of the cat's movements can be resolved with the standard television camera. Temporal resolution can be improved by solid state cameras, which are faster and permit more rapid scanning (Brugger & Milner, 1978).

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