Computer control of grating phase and movement

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A method is presented which uses an on-line computer to control the spatial phase and movement of an electronically generated grating display for visual experiments. This technique minimizes CPU overhead and is inexpensive. The method is compared with several other schemes for controlling grating phase and movement.

When vision researchers use grating patterns, the temporal modulation of the patterns is often important. Despite the trend away from optically generated patterns and toward CRT displays, it is difficult to move, jiggle, or displace patterns in real time. Most systems for temporally modulating gratings have been expensive and limited stand-alone devices; when computers have been employed, the task of producing a moving display has left the machine with little time to perform other tasks. We have developed a system useful to computer-based laboratories that resolves some of these problems. The system combines machine software with a minimum of hardware construction (one \$1.20 chip) and reduces the overhead on the CPU. Although we used a full-blown minicomputer for our implementation, all but the most primitive microprocessors can serve just as well. Consequently, the method should be of general interest.

The customary method of generating a CRT grating (Campbell & Green, 1965; Schade, 1950) is as follows: Function generators or other oscillators supply signals for each axis of the display. A high-frequency (approximately 50-100 kHz) triangle or sawtooth wave drives the CRT beam up and down along its vertical (Y) axis, generating a bright line; a ramp (sawtooth) waveform of much lower frequency (approximately 100 Hz) sweeps this bright line horizontally along its X axis. This generates a uniform bright field on the CRT screen. If the intensity (Z axis) of the display is then modulated, say, sinusoidally, vertical sinusoidal bars appear on the CRT. The number of bars is proportional to the ratio of the Z-axis frequency to the X-axis frequency. If the X-axis sweep oscillator is synchronized with the Z-axis signal, the grating is stationary. If it is not, the grating drifts across the screen, unless the Z-axis signal is an exact multiple of the sweep frequency. The drift rate of the grating can be controlled by manipulating the relative frequency of the sine and the sweep, but it is difficult to know how fast the grating is moving, and

the velocity is unstable. A slight shift in the frequency of either generator greatly affects velocity.

To stabilize velocity, some scheme must be used to synchronize the X and Z channels but allow a continuously variable phase relationship between the two waveforms. Such schemes require that the source of either the sweep or the intensity signal is triggerable.¹

One method requires the use of an electromechanical device called a synchro-resolver, which has two inputs and two outputs. When the sine and cosine phases of a sinusoidally varying voltage, $\sin(\omega t)$ and $\cos(\omega t)$, are input to the device, outputs are proportional to $\sin(\omega t + \theta)$ and $\cos(\omega t + \theta)$, where θ is the angular position of the shaft of the resolver. If a variable-speed motor is connected to the shaft, the output of the resolvers is proportional to $\sin(\omega t + \alpha t + \theta_0)$ and $\cos(\omega t + \alpha t + \theta_0)$, where α is the speed of the motor and θ_0 is the starting position of the motor. Thus, the output is constantly shifting in phase relative to the input. This output waveform is of poor quality but can be used as a sync signal for another function generator that provides the Z signal; the X-sweep generator is synced to one of the input waveforms. However, this system falls prey to the problems of most mechanical stimulus drivers; it is noisy, and the speed and direction of the motor is difficult to control and stabilize. The system generally requires a stroboscopic tachometer to precisely determine the speed of the motor and, hence, the grating.

A more promising approach is to build a type of specialized analog computer (Rogers, 1976). These devices electronically compute the expression for a moving grating. The expression for a grating moving relative to $\cos(\omega t)$ is:

$$\cos(\omega t + \omega' t) = \cos(\omega t)\cos(\omega' t) - \sin(\omega t)\sin(\omega' t)$$

where ω is proportional to the spatial frequency of the pattern and ω' is proportional to the temporal frequency of light modulation at a fixed point on the screen. Expensive high-quality multiplying and function generating modules are needed for these devices and they cannot produce arbitrarily slow speeds.

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Brown (1977) has proposed a digital device that measures the period of a waveform and produces the necessary series of delays between triggering the X sweep and the Z signal. The chip count (26 ICs and 40 discrete components), and hence the cost, is still high. It has the advantage of no lower limit on the range of velocities it can produce, but, as with the other techniques, it can produce only one type of temporal modulation—linear movement. The chief attraction is that no computer is required.

If a researcher possesses a reasonably fast lab computer, he can attack the problem of phase control directly by using his machine as a function generator to supply the Z-axis signal. Srinivasan and Bernard (1977) used this technique to study the optokinetic response of the fly. They digitally computed and stored their grating pattern, then sequentially outputted the values of the function to the display via a digital-to-analog converter (DAC), while another DAC produced the X sweep. By controlling which number in the table of Z values was output along with each point along the X sweep, they controlled the phase of the pattern from frame to frame. They elected to produce motion, but any phase change can be produced this way (jiggling, random phase, etc.). However, the computer must run at close to full speed, simply outputting values of the function, and has little time available to sample physiological or psychophysical data from the subject viewing the display (Cleland, Note 1). It is especially important to be able to measure eye movements while the display is on so that the true displacement of the image across the retina may be known.

We suggest a method for the computer control of the phase and movement of a grating display that puts very little demand on the computer's time yet retains the advantages of the Srinivasan and Brown technique. Moreover, there is no lower limit on the velocity range obtainable and the upper limit can be extended beyond the point of experimental usefulness.

Figure 1 is a functional block diagram of our system and Figure 2 illustrates the waveforms generated by each component. The computer (DEC PDP-8/I) initiates a frame of the display by generating a sync pulse, waveform (a) in Figure 2. (Hereafter, a letter in parentheses refers to the waveform in Figure 2.) At some time during the frame, the computer must also change the voltage output (b) of the DAC. These are the only essential duties of the machine for each frame. The sync pulse directly triggers the ramp generator, producing the X sweep (f). The (a) pulse also controls the sine-wave generator that modulates the raster (Z signal). But, in this case, a delay is introduced in the signal by two timers wired as one-shots (the 556 timing chip). The (a) pulse causes OS_1 to fire (c). The duration of the pulse is determined by the voltage from the DAC. The training edge of the (c) pulse triggers OS_2 , which produces waveform (d). This in turn activates the Clarke-

Figure 1. Functional block diagram of the system. OS_1 and OS_2 are one-shots and X, Y, and Z are three function generators that generate the CRT display. The waveforms produced at points a through f are illustrated in Figure 2.

Figure 2. The waveforms produced at points a through f in Figure 1 and the timing relationships between them.

Hess generator (Model 748), which is operating in the tone-burst mode; the generator produces a sine wave (e) whenever OS_2 goes high—and always a sine wave of the same phase relative to the leading edge of (d).

Comparing waveforms (e) and (f) shows that the delay between the start of each increases with each frame so long as the DAC voltage increases. When the pattern has moved by one spatial period, the DAC voltage resets to its initial value and repeats. Since the pattern is repetitive, the bars appear to be moving continuously.

Prior to producing the display, the computer must store the table of values that go out over the DAC (b). The temporal frequency of (b) equals the temporal frequency of the pattern. The velocity equals the temporal frequency divided by the spatial frequency of the pattern. Thus, a digital ramp frequency of .5 Hz and a spatial frequency of 10 c/deg would produce a velocity of .05 deg/sec. The amplitude of (b) must be calibrated so that it produces a shift of exactly one period; otherwise, the movement will be jerky. A separate calibration program allows us to adjust this amplitude until the movement looks smooth. The machine controls the frequency of the Clarke-Hess generator and the program has a table of calibrated (b)

amplitudes for each frequency. If the frequency of the generator is calibrated accurately after warm-up, movement at all speeds and spatial frequencies is smooth and remains so for hours.

The frame rate, and thus the frequency, of the sync pulses (a) was 140 Hz. This means that once every 7 msec the machine devotes about a tenth of a millisecond to the display. The rest of the time the computer monitors physiological and psychophysical variables in the experiment or generates new tables for the display.

This system can do more than produce linear movement. If one generates a (b) waveform of decreasing rather than increasing voltage, the movement is in the opposite direction. A triangle waveform produces an oscillating grating. We have also used the device to produce a stationary grating whose phase is random from trial to trial to investigate the effects of phase uncertainty.

In summary, this system allows the complete control of the phase of the CRT grating display. The system is also inexpensive, provided the computer, function generators, and scope are already handy. Wiring the integrated circuits requires little electronic skill and the computer programming is not difficult. The outstanding feature of the system is its "set it and forget it" quality, which frees the CPU for more important tasks.

REFERENCE NOTE

1. Cleland, B. G. Personal communication.

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NOTE

1. Stability and control might be imposed under these conditions by the use of a phase locked loop (PLL) integrated circuit. Normally this device is used to "lock" the frequency of an oscillator to the frequency or harmonic of a reference signal. The PLL produces an error signal proportional to the difference between the two, and this error signal then feeds back negatively to control the frequency of the oscillator. However, a PLL could be used to lock the Z-axis signal to some stable noninteger multiple of the X-axis frequency, and thus the velocity of the bars would be stable. As far as we know, this idea is untested.