Communications

Time-Compressed Video Pictures for Vision Research

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Abstract—**An interface is presented that uses time compression to allow static TV pictures (picked up by standard video-processing systems or synthesized by software) to be displayed at a rate of about 500 frames per second.**

Time compression of the video signal is achieved in two steps. The digitized video-information is first loaded into the memory buffer of the device, the video memory. After completing a computer-aided loading cycle, the device is switched to the automatic reading mode, in which the video memory is read sequentially at a rate of 8 million words/s. Since the format of the picture is 128 × 128 pixels, the time compression factor, as compared to standard video signals, is about 10.

The values of the device parameters (repetition rate, format, and gray tones number) were chosen to meet the requirements of a specific application in the field of vision research: the presentation of complex figures with high information content as stabilized images or, more generally, in the variable retinal feedback condition.

INTRODUCTION

The choice of stimuli is a critical step in the planning of those experiments whose purpose is the study of human vision.

The facilities available nowadays for computer-assisted generation and processing of images could be profitably exploited to design a general purpose stimuli generator, provided that all useful visual stimuli could take the form of video pictures.

Owing to their sequential nature, however, video pictures cannot be used when the image generation must be completed in a time shorter than some tens of milliseconds. For example, it is apparent that standard TV pictures cannot be flashed for very short time intervals. Although less obviously, they cannot even be yoked to eye movements to vary the gain of the retinal feedback path [1]. Since the frame period is comparable to, or larger than, the duration of the fastest eye movements (i.e., saccades), an image splitting might result from the interference between the raster and the driving signals [2].

The signal interference can be avoided by rising the scanning frequency by about one order of magnitude. As an example, an ad hoc camera could be designed using an image dissector to make the output video signal indepenent of the scanning frequency [3]. In so doing, however, the facilities provided by the above-mentioned commercial computer-assisted image-processing systems could not be utilized. In order to use such facilities, one could shift a standard video signal to a higher frequency band by using time-compression techniques. This is precisely the method we applied to design the FAST generator described in this paper.

The FAST generator was specifically intended for the variable retinal feedback application. This method is an important tool for research on the human oculomotor and visual systems [4], [5]. In fact, by changing the natural relationship between eye movements and the movements of the retinal image, the method allows one to induce reversible harmless modifications in the acquisition stage of the visual process. The resulting behavioral changes, like the effects of pathological misfunctions, can bring into evidence physiological and perceptual mechanisms otherwise undetectable under normal conditions [6]-[11].

In accordance with the planned applications, the FAST generator performs a time compression of a standard video signal of about one order of magnitude so that a 128 × 128 pixel window of a video picture—4 bits per pixel—can be displayed at a repetition rate of about 500 Hz.

SYSTEM DESCRIPTION

The principle of operation of the FAST unit is a very simple one. A standard picture synthesized by software or picked up by a standard video processing system is stored in the memory of a computer. The computer transfers a picture window into a fast-access-time memory buffer, i.e., the video memory of the FAST unit. The video memory is then read sequentially at the rate imposed by the selected time-compression factor, thus generating a high repetition rate video signal.

System Parameters

The actual design of the FAST unit depends on the values assigned to the following parameters: time-compression factor, format, and gray-levels number. The first two parameters determine the operating frequency of the unit, while the size of the video memory is set by the second and third parameters.

As explained in the Introduction, the value of the time-compression factor must be about 10. As regards the picture format, let us recall that the variable retinal feedback method requires the FAST picture to move on a display screen as it is driven by eye movements. Accordingly, not only can the picture not fill the screen, but the larger the desired range of the picture excursion on the screen, the smaller the picture size should be. A good compromise between image excursion and image size can be reached by choosing a value of 4 for the linear scale factor between image size and display size. As a result of this choice, a 128 × 128 pixel FAST picture will have the same resolution of a 512 × 512 standard one.

Once the 128 × 128 picture format has been selected, a memory reading cycle will take 2^{14} clock cycles to be completed, so that at an operating frequency of 8 MHz, the repetition rate of the output video signal is 488 Hz (at a line frequency of 62.5 kHz) and the compression factor is 9.8

Finally, if 4 bits are used to codify up to 16 different gray tones, a 16 × 4 kbyte video memory capacity will be required.

Functional Description

The main functional blocks in the FAST generator are the video memory, the input decoder, and the display controller (Fig. 1).

1) Video Memory: Memory addressing is assigned to the computer, through the input decoder, for memory loading (write mode), and to the display controller for memory reading (display mode).

The row/column type of addressing organization was preferred to the sequential one for programming ease. In fact, it allows the video memory to be viewed as an ordered matricial representation

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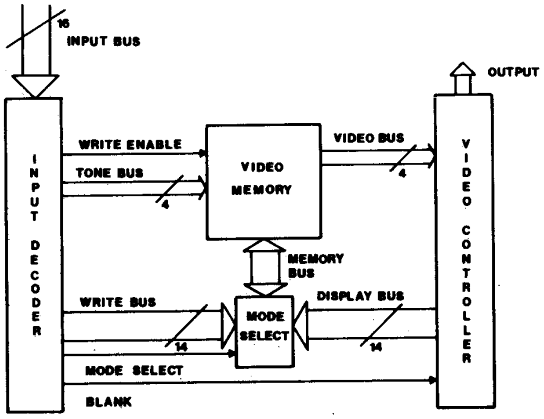

Fig. 1. Block diagram of the FAST generator.

of a video picture since the gray tone of each pixel $p(x, y)$ is stored in the memory location whose row and column addresses are y and x, respectively. As a result, all the address busses have physically separated row and column lines.

2) Input Decoder: The input decoder is assigned computer-aided video memory loading.

The decoder is fed by the computer through the input bus (Table I), consisting of 8 data lines and 8 control lines. The data lines convey either the row/column pixel address or the pixel gray tone. The control lines convey data-transfer control signals that lead the decoder operation so that the gray tone of each pixel can be stored in its proper memory location.

The decoder functions can be summarized as follows:

1) it sets the display (write) mode of operation by enabling the mode multiplexer to switch the memory address bus to the display (write) bus when the mode select line is high (low);

2) it enables the transfer of the input word to the row or column lines in the 14-bit write bus or in the tone bus depending on which data enable line is high;

3) it enables the loading of a given gray tone in the addressed location of the video memory while the write enable line is low;

4) it disables visualization, both in the write and the display modes, when the blank line is low.

3) Display Controller: It provides automatic memory reading and generates appropriate accessory signals.

Once the input decoder has enabled the memory address bus to be switched to the display bus, the video memory is addressed by a 14-bit counter in the display controller, actuated by the system clock. Since the column lines in the display bus carry the 7 less significant bits of the counter output, the column address will rise, step by step, one step every clock cycle, from 0 to 127. The row address, carried by the seven more significant bits of the counter output, increases accordingly from 0 to 127, but each step occurs only every 127 cycles. Then the video memory is addressed sequentially, row by row. The output signal after D/A conversion is the desired time-compressed analog video signal.

The display controller also provides vertical and horizontal scanning signals (synchronized to the video signals) by performing D/A conversion on the row and column lines of the counter output. Finally, the display controller can generate horizontal and vertical blanking signals (synchronized to the video output) by performing simple logic functions on the column and row lines of the display bus.

Since the operation of the display controller is continuous, video- and raster-signal generation occurs in both the write and the display modes. Accordingly, a meaningless picture is displayed while the write mode is operative since the gray tone of the pixel addressed by the write bus is assigned to the pixel concurrently addressed by the display bus. To prevent visualization, the input decoder must enable the display controller to clamp the video output at a suitable blanking voltage. Visualization can also be disabled in the display mode to allow for a software-controlled choice of the picture presentation time.

TABLE I
SIGNAL ASSIGNMENTS TO THE INPUT BUS

Lines 0–2	Address bits 0–2	
3–6	Address bits 3–6 or data bits 0–3	
7	—	
8	Mode Select	
9	Data Enable:	row address
10		column address
11		gray tone
12	Write enable	
13	Blank	
14–15	—	

Hardware

In order to increase the reliability, the FAST unit was implemented on two printed circuit boards (Fig. 2). Very fast components were selected to avoid critical operation conditions: The Hitachi HM6147HP-35 static CMOS RAM with a read-cycle time of 35 ns was chosen for the video memory (16k × 4), and the TRW TDC1016J-8 was chosen for the video converter, whose conversion rate is as high as 20 megasamples per secnd (MSPS). Conversion rates of 20 and 1 MSPS characterize the 7-bit D/A converters used in the display controller section to generate the sweeps for horizontal and vertical deflection signals.

Since the format of the picture is one order of magnitude smaller than a standard format and the repetition rate is one order higher, the bandwidth of the time compressed video signal is the same as for a standard video signal, thus facilitating the design of the video amplifier.

Environments

The FAST generator was designed as a subunit of a general purpose programmable generator of visual stimuli using a DEC MICROPOP11 computer (1024-kbyte resident memory). The communication between the computer and the FAST unit is ensured by an I/O DEC DRV11 parallel line interface. A MATROX pictorial video-graphic system (including a QVAF512 master board and two QRGB GRAPH slaves) is installed on the MICROPDP11 and allows single frames of video information from a camera or a video recorder to be loaded into the display memory of the graphic controller board where it can be modified by the user's software. Images can also be synthesized by points and lines. A vector generator and a color lookup table provide facilities for software procedures. The video-graphic system allows for a maximum picture format of 512 × 512 pixels (8 bits per pixel).

The FAST unit can also be operated by an 8-bit microcomputer that will alternately feed the data and the control lines in the input bus.

SYSTEM SOFTWARE

From the software point of view, the FAST unit is a write-only 16-bit register that is loaded by the computer through the DRV11 parallel interface. As a matter of fact, this virtual register represents the FAST input bus so that each bit has the same meaning as the corresponding line in the bus (Table I).

The main function of the system management software (written in MACRO 11) is to run the loading of the video memory. The memory can be loaded either in random order or sequentially, row by row. The first procedure is used to load very simple synthesized figures with a uniform background, or to change a few pixels in a picture stored in the video memory. The second procedure is suitable to transfer into the FAST unit a 128 × 128 window of a video picture stored in the MATROX display memory.

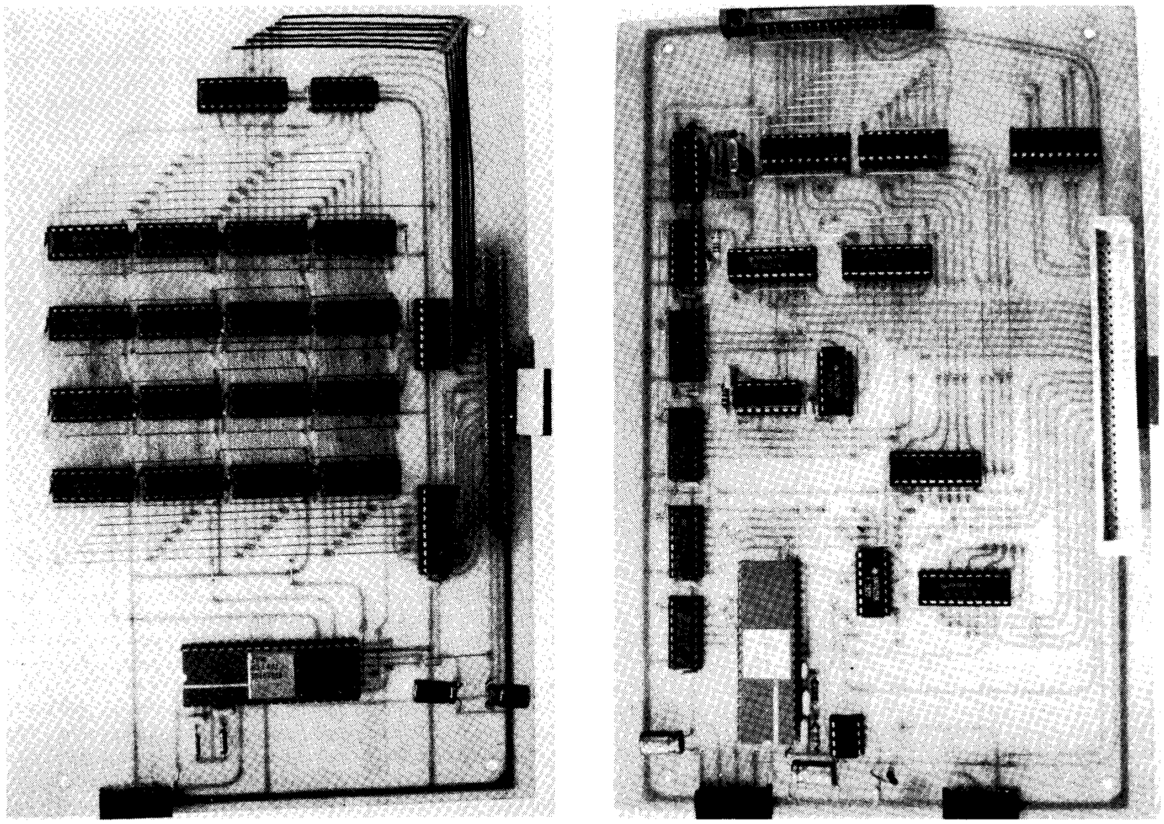
(a) (b)

Fig. 2. Component side of the two FAST generator boards. The interboard wire connections are visible by transparency. (a) The video memory and the D/A video converter, (b) the input decoder and the video controller.

TABLE II
THE ELEMENTAL COMMANDS

Command		Description			
Mnemonic	Octal code	Mode	Operand	Memory Loading enabled	Blank enabled
ENX	12000	Write	column address	no	yes
ENY	11000	Write	row address	no	yes
ENG	14000	Write	gray tone	no	yes
INID	10000	Write	—	no	yes
EXDI	30400	Display	—	no	no
WRIT	00000	Write	—	yes	yes
BLANK	10400	Display	—	no	yes

Both procedures involve simple routines which perform the loading of one pixel in the appropriate memory location and are run repeatedly. Such routines must lead the execution (in a proper sequence) of some of the functions of the input decoder that are listed in the system description. Accordingly, the routines use a set of elemental "commands" (listed in Table II) that, by codifying the above mentioned functions, ensure a correct communication between the computer and the FAST unit. Note that the low-order byte of each elemental command is always 0. The data (row or column address and gray tone) are coded in the low-order byte of a "data word" (Y, X, G) whose high-order byte is identically zero. When a data word (X, Y, or G) is ORed with the corresponding data transfer command (ENX, ENY, or ENG), a "composite command" is obtained that contains both a datum and the specifications for its use by the FAST unit.

An example of single-pixel loading routine (SPL) is outlined in Fig. 3, by showing the sequence of commands (elemental or composite) that are sent to the virtual register by the routine. A random loading procedure will contain as many calls to the SPL routine as the number of pixels to be written in the memory.

TABLE III
COMMANDS AND ROUTINES USED BY THE SEQUENTIAL LOADING PROCEDURE

Instruction	Command
Set the write mode	INID
Set the display mode	ESDI
Move *VY* to the row lines in the Write Bus	ENY + *VY*
Load the gray tone in (*VX*, *VY*)	ENX + *VX* → ENG + *G* → WRIT → INID

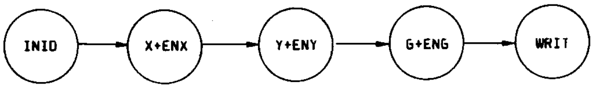

Fig. 3. Sketch of a single-pixel loading routine, showing the sequence of commands outputted to the parallel interface.

The flow chart of the currently used sequential loading procedure (the actual language is MACRO 11) is shown in Fig. 4. Two couples of registers, *VX* and *VY*, *DX* and *DY*, are used to point to the memory locations in the FAST video memory and in the MATROX display memory, respectively. When initialized, registers *DX*, *DY* point to the starting address of the selected 128 × 128 window in the MATROX display memory. A memory location is represented by its column and row addresses, separated by a comma and closed within parentheses. The above-defined commands as well as a routine very like SPL are used in the "enable," "move," and "load" program steps, as shown in Table III.

If the FAST generator is driven by an 8-bit computer, the FAST unit is seen as an 8-bit register so that one-byte data and instructions must be defined and sent in sequence to the FAST input bus. The number of I/O calls and the memory-loading time is increased accordingly.

CONCLUDING REMARKS

The operation of the FAST generator prototype is very reliable, and its programming is simple and direct. Because of the high-repetition rate, the time-compressed video pictures are inherently flicker-free and exhibit a striking stability.

Time-compressed video pictures can be flashed for time intervals as short as the frame duration (about 2 ms), by actuating the input decoder blank function. The displayed pictures cannot, however, be changed at comparably short time intervals because of the interdisplay dead time, that is the time required to load each new picture into the video memory. As explained previously, a meaningless picture is displayed during this time interval, except when visualization is disabled by the input controller. The upper limit to the dead time is about 0.7 s, which is the time required to store in the memory a 128 × 128 picture drawn from the MATROX system by using the procedure outlined in Fig. 3. Since the loading time is roughly proportional to the number of pixels to be actually loaded into the memory (about 60 μs must be spent for each pixel), the fewer the pixels whose gray tones have to be changed are, the lower the interdisplay dead time.

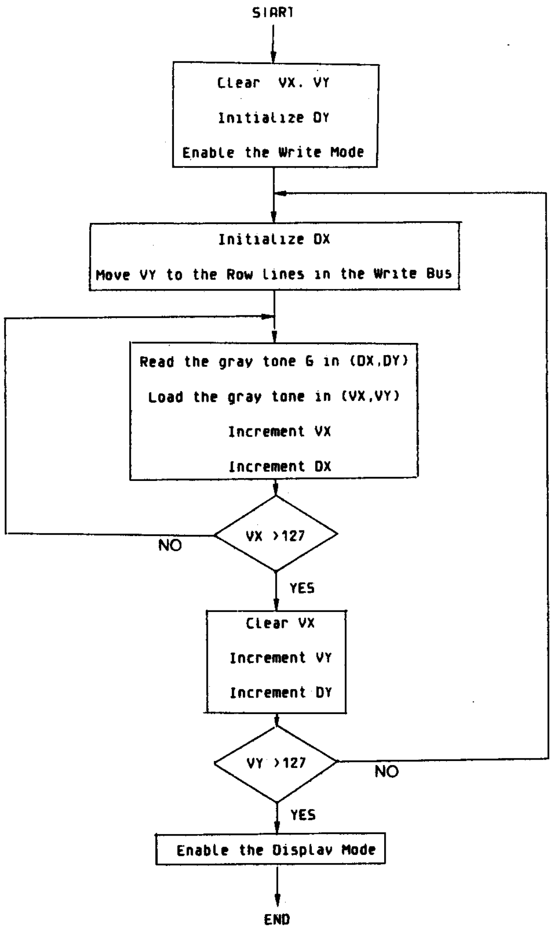

Fig. 4. Flow chart of a sequential, row by row, loading procedure.

Anyway, the interdisplay dead time does not cause any trouble to the variable retinal feedback application since the stimulus does not usually change in the course of a test, and the test duration is on the order of a few minutes.

The design of the FAST unit can be improved in several ways to reduce the dead time. By giving up the compatibility with 8-bit computers, for example, the row and column memory addresses can be coded together in a 16-bit word so that calls to the parallel interface can be avoided. Furthermore, an option for automatic sequential memory addressing in the write mode can be implemented by duplicating the display controller circuitry that addresses the video memory in the display mode. In this way, only the gray-tone data transfer will be performed by the system software. These and other improvements (such as 256 rather than 16 gray tones) will be implemented in the second version of the FAST generator that is presently under construction.

As a final remark, we want to point out that, in principle, the picture format could be increased from the actual 128 × 128 pixels up to 256 × 256 or 512 × 512, without any change in the unit design. It will suffice to replace each component with a suitable faster one and to increase the video memory accordingly. As a matter of fact, a definite limit to the format increase is imposed by the line frequency which, for a 512 × 512 format and a frame repetition rate of 488 Hz, will be as high large as 1 MHz, thus causing the bandwidth of the video signal to reach extreme values.

A complete hardware description and examples of control software are available from the authors.

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Latency of the Pupillary Response

NORMAN LINK AND LAWRENCE STARK

INTRODUCTION

Pupillary latency represents time delays in retinal conversion of the light stimulus conversion to nerve impulses, time dalays due to nerve transmission, and neuromuscular excitation and activation delays [8], [9].

This paper will give a useful explanation of latency in terms of nonminimum phase lag. The minimum phase lag is that phase associated with a simple linear lag element; nonminimum phase is associated with a true delay element modeled as exp (−ST); latency, a term widely used by biologists, can be accurately modeled by a delay element. This was first done by Stark in 1959 [1] when using sinusoidal light inputs he calculated a transfer function to describe the pupil. The linear third-order model that was introduced only accounted for the minimum fraction of the total phase shift observed in the experimental data. In order to account for the nonminimum phase portion of the total phase shift, an exp (−ST) term was introduced. This model gave rise to the idea that pupil latency was not a function of stimulus frequency but only of the light stimulus intensity [2]–[7].

This paper will experimentally demonstrate that pupillary latency increases with reductions in intensity and increases with frequency of the square wave stimuli. A model is put forward to summarize these characteristics.

METHODS

Measurements made for this research were taken using a TV pupillometer. A subject's pupil was monitored using an infrared camera and light while the other pupil was subjected to various stimuli. It has previously been established that the pupil consensual reflex to light is synchronous with the direct pupil reflex to light [1]. The video signals were fed into a microcomputer where the location and size of the pupil was calculated and recorded.

Our interest in measuring pupil latency required that we examine the delay inherent in the video pupillmeter. Depending on when the event takes place in relationship with the video frame rate, the delay attributed to the pupillometer is about 40 ± 10 ms. All references to latency in this paper have had 40 ms subtracted from it to reflect this delay. This leaves each measurement with a ±10 ms error.

The stimulus used for these experiments was square wave light pulses. The intensity of the light stimulus was controlled over logarithmic ranges with neutral density filters. Stimuli used for these experiments (Table I) ranged from 0.1 to 10 fL. The light beam was shone through the pupil in what is termed "Maxwellian view." This means that all of the light stimulus is focused through the center of the pupil so that regardless of the pupil's response, the amount of light striking the retina remains constant. The use of square waves was important so as to avoid any controversy in our definitions of latency. For the duration of this paper, we have defined the frequency of the square wave stimulus as "repetition rate" (rep. rate). It should be noted that although the repetition rate is analogous to frequency, it is by no means equal to it.

The definition of latency used in this paper is one of the IEEE standards and is illustrated in Fig. 1 [10]. Due to the abrupt initial response of the pupil, the latency is well defined, and it is defined as the time between the onset of the input stimulus and the onset of the pupillary response. The minimum latency (usually referred to as rise time) corresponding to the minimum phase lag is defined as the time between the onset of the pupillary response and the time when 90 percent of the maximum response has occurred. By using the following formula we have translated the latency into nonminimum phase.

$$\text{Phase (nonmin.)} = \left\{ -\text{Lat.} \times (\text{Rep. Rate}) \times 360 \right\} \text{ degrees.} \tag{1}$$

RESULTS

The results of the experiments show that latency is a function of both the light stimulus repetition rate and intensity [Fig. 2(a) and (b)]. Fig. 2(c) and (d) shows nonminimum phase as a function of light stimulus repetition rate and intensity. In order to see how latency and nonminimum phase are functions of both repetition rate

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