An Intelligent Video Pattern Generator for Use in Ophthalmology

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Abstract

A new video pattern generator for use in ophthalmology is designed and constructed. Among the capabilities of the system is the generation of dynamic and static random element stereograms that can be used to test stereopsis (depth perception) in infants and noncommunicative people. Other patterns that can be generated by the system include checkerboards, and vertical and horizontal bars. The sizes of the checkers and bars can be zoomed in or out at any required rate. The system is based on the TMS 34010 , a powerful graphics processor that operates at 40MHz. The system software is written in assembly language which provides fast speed of operation.
The system is efficient, and versatile at reduced cost.

I. Introduction

The eye is one of the most important parts of the human communication sensors. In fact, it determines more than 50% of the data captured by the human [1,2]. The eye is responsible for recording images that surround the human being which are further analyzed by the brain to recognize various objects in the image. Why do humans have two eyes? This question is answered by the fact that an easy way to perceive depth of objects is to look at it from two different angles (binocular vision). Thus, a human can perceive depth by combining the images seen by both eyes.

Stereopsis can be tested by means of a random-dot stereogram which consists of two images that when viewed monocularly (with one eye) appear completely random, and when viewed binocularly (one image viewed by the left eye and the other by the right eye) the correlated points from the left and right images are seen in depth. Thus, the eye diffuses the two images to produce a 3-Dimensional image. The depth of objects is controlled by the disparity between the location of the points in the two images. A convenient method to provide separate stimulation of the eyes is the Anaglyph method. In this method, the two halves of the stereogram are of different color and the stereogram is viewed with the appropriate color filters placed over each eye.

Tessman [3] discussed the methods to form stereo perspective projections, and how to implement them in software on a very high speed and costly workstation. The study of stereogram generation has been attractive to researchers. Julesz and Johnson [4] devised an algorithm to generate a single stereogram for two or more surfaces. Julesz [5] described a method to scramble text. When the images are viewed monocularly, text is seen clearly, while when they are viewed binocularly nothing is seen. Furthermore, he discusses the suppression of monocularly perceivable symmetry during binocular fusion. Wixson [6] proposed a stereoscopic workstation for visualizing transparent three dimensional volumes of data. Mizuno [7] described a system in which the stereogram images were displayed on two CRT oscilloscopes (each eye views one of the images). This system is not efficient due to the inconvenience of using optical techniques to view the two images. Shetty et al [8] presented a pure hardwired stereogram generation system that displays images on a color monitor. However, the system was fixed in terms of stimulus parameters. Obaidat [9,10] devised and designed a new architecture for dynamic

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and static stereograms generator. However, the system has some limitations such as limited disparity range, and inability to generate other patterns.

II. Design Methodology:

The design objectives are speed, resolution, flexibility, versatility, and compactness at reduced cost. In fact, the hardware layout of the system is much smaller than previous designs, although many extra features were added to the system. Furthermore, the system is versatile with its ability to produce many video patterns that are needed for vision tests.

To avoid flickers in the screen, the system must display a minimum of 30 NTSC video frames per second (or 25 PAL/SECAM video frames per second). For a resolution of 1024 x 512 (524,288 pixels per frame) this corresponds to 15.36 million pixels per second. A microprocessor is unable to produce that amount of random data without the aid of external hardware circuitry. Furthermore, the red and green pixels should be delayed apart to produce a stereogram.

Based on the previous requirements, a video manipulation circuit is added to the microcomputer system. Moreover, the TMS34010, a powerful graphics processor from Texas Instruments, was used to control the system. The processor has special features that enhance the speed of graphical manipulations. The video manipulation circuit performs the tasks of generating random numbers and delaying the green signal from the red signal according to the required disparity. Each pixel data contains information regarding whether the pixel is random or not, and whether the green signal should be delayed for that specific pixel. The whole circuit is also controlled by the control register which determines the amount of disparity, enables the video manipulation circuit, and controls the reset input of the random number generator to produce either dynamic or static stereograms. When the video manipulation circuit is disabled, the system acts as a normal high performance graphics system.

The design utilizes the TMS44C251 video RAMs (VRAMs) and TMS34070 color palette which further enhance the performance of the system. The processor stores the image information in the VRAMs through their random access port. Furthermore, the processor performs a screen refresh cycle whenever needed. During a screen refresh cycle, pixel data are transferred from the memory of the VRAMs to serial shift registers which are also part of the VRAMs. Usually this data can be used to scan several screen lines. During normal operation, the pixel data are shifted out serially from the shift registers to the video manipulation circuit. Then they are passed to the color palette which uses the data to generate the RGB signal going to the color monitor. The following sections describe the system's building blocks in more detail.

III. Hardware Circuits

A simplified block diagram of the system is shown in Figure 1. A brief description of the architecture is given below.

The heart of the general purpose stereogram, shown in Figures 1, is a TMS34010 graphics system processor developed by Texas Instruments (TI), operating at 40 MHz. The key features of the TMS34010 are its high speed, high degree of programmability, and efficient manipulation of hardware-supported data types such as pixels and two-dimensional pixel arrays [11].

This memory interface part of the system handles the decoding needed to access the various memories which include the Dynamic Random Access Memory (DRAM), the Video Random Access Memory (VRAM), Universal Asynchronous Receiver Transmitter (UART), Control Register and the Read Only Memory (ROM). Furthermore, it includes the circuits necessary to latch and buffer all data lines and address lines which are multiplexed on a 16 line bus.

The system uses two 8-kbyte Erasable and Programmable Read Only Memory (EPROM) chips to hold the monitor program which is necessary to start up the system. The monitor includes routines to initialize the system, load user programs, execute user programs, and other debugging instructions.

The EPROMs can also be used to store permanent information and pattern generation routines that are used frequently. This would provide a library for the programmer who will need to call these routines from his/her program. Thus less programming and setting efforts would be needed by the user to generate a test experiment.

The RAM system includes eight 64k x 4 DRAM's (TMS4464), which gives the user 256-kbytes of RAM. The RAM is used to hold the user programs, general variables, and intermediate results. Moreover, it is used to store extra video frames.

The display memory has four 256k x 4 VRAM's. It is designed to hold two 1024 x 512 pixel frames or four 512 x 512 pixel frames. Each pixel is characterized by 4-bits of the VRAM. The contents of the 4-bits are interpreted depending on the operating mode. During the normal operating mode, the 4-bits determine the color code of each pixel. Thus each pixel may be one of 16 predefined colors. The 16 colors are defined at the beginning of each frame sent to the color video monitor. In the stereogram mode the 4-bits describe the state of each pixel. The VRAMs generally provide two functions to the system: 1) Storage of the video frame information; 2) Supplying of video frames to the monitor or video manipulation circuit, depending on the mode of operation. Figure 2 shows the pixel definition format.

The random number generator is used to generate a stream of pseudo random bits for the red and green video signals. This is used to generate the static and dynamic random dot stereograms. The generator supplies random bits at the speed of the video clock.

The random number generator utilizes Linear Feedback Shift Registers (LFSR) to generate a sequence of random pulses that are repeated with a period of 2^n-1. The LFSRs have been in use for a long time for error-control coding, VLSI testing, spread spectrum communications, etc. The LFSR used in this work can be represented by the irreducible polynomial :

$$f(x) = 1+x+x^2+x^7+x^{24}$$

A processor is unable to produce such a large amount of random data. Hence, this circuit has been added to the system which operates in the background, freeing the processor for other tasks, and hence improving the overall speed of generation.

To produce a stereogram, the delay circuit must delay the green signal coming out of the display memory or the random number generator. The amount of delay is determined by the three least significant bits of the control register. Furthermore, the delay is enabled by the pixel data, such that only pixels that will appear in depth are delayed. This circuit was also needed since the pixel data might be generated by hardware. Thus, pixel manipulation needs to be done by hardware too.

The color palette encodes the digital data coming into it from either the display memory or the delay circuit. It produces the red, green, and blue analog signals that are fed to an RGB color video monitor. At the beginning of each frame sent to the screen, the data coming out of the display memory defines the amount of red, green and blue associated with each one of the 16 colors that can be displayed on the screen. This provides 4,096 different colors but only 16 of them can be displayed at one time.

An NTSC RGB monitor is used to display the various patterns generated by the system. Any RGB NTSC color video monitor can be used, however, the system displays 1024 x 512 pixels. Thus best results will be obtained if a 1024 x 512 RGB monitor is used.

The host computer used in this system is an IBM compatible 386-PC. Any other personal or mainframe computer that has an RS-232C serial interface can be used. The host computer is used to provide a better user interface. Due to the large software available on the IBM PC, user interface software can easily be developed. The host communicates with the system through an RS-232C serial interface. This interface allows flexibility to connect the system to another personal computer such as the Apple Macintosh.

The MC68661 Universal Asynchronous Receiver Transmitter (UART) was used to interface the board to the host computer through an RS-232C interface.

The video manipulation circuit was added between the color palette and the VRAMs to enable the system to generate the Random Dot Stereograms. This section of the circuit includes an 8-bit Control Register enabled at address $(04,000,000)_{16}$, which has several purposes. Figure 3 shows the bit definition of the control register.

The Mode bit determines whether the system is operating in the stereogram mode or in the normal mode, a one indicates normal mode. The dynamic bit determines whether the random dots are dynamic or static (i.e. Whether the color of the pixel changes from one frame to another or remains the same in all video frames), a one indicates dynamic random pixels. The three disparity bits determine the amount of delay between the red and green signals as shown in Table 1.

In the normal mode all data from the VRAMs are passed directly to the Color Palette without the intervention of the Video Manipulation Circuit. However, in the Stereogram mode, the four data bits for each pixel serve a different purpose. The least significant bit determines whether the pixel has a red component or not. Bit 1 determines whether the pixel has a green component or not. Bit 2 determines whether the pixel data should be taken from the random number generator, which will override the red and green components by a random number. The most significant bit determines whether the red component of the pixel should be delayed or not.

The delay circuit is built using two 8-bit shift registers. One of the registers is used to delay the green signal of the odd pixels and the other is used to delay the green signal of the even pixels.

IV. Application Software

These random dot patterns allow physicians to test people for binocular vision disorders such as lack of stereopsis. The pattern may be generated such that when they are monocularly viewed, the dots appear as formless random textures. However, when viewed binocularly, any shape, letter or object may be perceived above a background in vivid depth. These patterns can be in a static form where the random pattern is generated once on the screen and stays the same during the testing period. Dynamic patterns change at the rate of 30 times per second which totally removes any monocular cues.

Furthermore, the object which is perceived in depth can be moved around the screen. This is very useful when testing infants, since the infant will tend to follow the object if he/she perceives it. By amplifying the visual evoked potential of the infant and comparing it with the object movement, the physician can determine whether the infant developed binocular vision. The system has the flexibility to vary the depth at which the object is perceived to one of 8 preset values. The system is not limited to generating random stereograms but can also be used to generate almost any stereogram that has two levels of depth.

In fact, random dot stereograms are only visible (fused) when the disparity is below six minutes of visual arc (3 pixels when an image of 512 pixeles wide is displayed on a 14 inch monitor and is viewed at a distance of one meter) [2]. However, if the stereogram is fused initially with a low disparity, and then the disparity between the left and right images is increased gradually, failure of fusion and the disappearance of the stereogram occurs at 2 degrees of visual arc. When fusion fails, the left and right images will breakaway. Finally, refusion of the two images will not occur, unless the disparity is lowered below six minutes of arc. For vertical disparity, breakaway occurs at 20 minutes of arc, while refusion occurs at six minutes of arc.

Figure 4 portrays a random dot stereogram generated by the system. The Figure can be viewed by placing a red filter on the right eye and a green filter on the left eye. When fusion occurs, the viewer should see a rectangular form in the middle of the picture coming out of the background. The disparity of this form is four pixels.

The system is able to generate a black and white checkerboard. The black and white checkers can be programmed to switch colors 30 times per second. The system can display 512 by 512 checkers. On a 14-inch monitor, and at a distance of one meter this corresponds to 10.8 cycles per degree and 23.7 degrees of visual arc. The checkerboard can be programmed to sweep from 2 x 2 checkers per screen (1 cycle) to 512 X 512 checkers (256 cycles). This is useful for acuity study. Figure 5 portrays a checkerboard pattern generated by the system.

The subject is able to distinguish minor breaks (dislocations) in a line that are fractions of the visual resolution. This is called "Vernier Acuity", while the visual resolution is called the "Visual Acuity". Stereoscopic Acuity is the vernier acuity when the breaks occur in depth. It was found that vernier and stereoscopic acuity are 20 seconds of arc.

The generation of the sweeping horizontal and vertical bars is very similar to the sweeping checkerboards, instead of having black and white checkers the pattern consists of black and white stripes. The system can sweep from 2 to 512 horizontal bars (256 cycles) and from 2 to 1024 vertical bars (512 cycles). When viewed on a 14-inch monitor at a distance of 1m this corresponds to 10.8 cycles per degree for horizontal bars and 15.8 cycles per degree for vertical bars. Figures 6 portrays the vertical bars pattern. This patterns is also useful in determining vertical and horizontal visual acuity.

The system can also generate the described patterns at one of sixteen contrast levels. By programming the system to sweep the contrast levels on a reversing black and white checkerboard, contrast sensitivity of the human eye can be studied.

V. System Software

A monitor program was written to simplify the development stage. The monitor program provides several functions such as: downloading a program from the PC, memory examine and change, running a program, registers examine, and software trap for tracing.

The downloading subroutine accepts the Intel's 32 bit hex format. Each line of the hex file is read through the serial port. The routine extracts the address at which the data should be placed, then extracts the data and places it at the appropriate locations.

The memory examines and change subroutine, requests the memory location to be examined. Then, the value at that location is displayed. The routine prompts the user for one of three possible responses. First, the user can change the data by pressing the space bar, then entering the new data. Second, if the character "." is pressed, the monitor ends the memory examine and change routine and control is returned to the command prompt. Any other key will allow the user to examine and change the next memory location.

The run routine requests the start of execution address and transfers control to that address. The register examine routine displays the contents of all CPU registers in hex format. Finally, the software trap allows execution to return to the next instruction following a TRAP 31. Thus the programmer can place the TRAP 31 at the required places. When the CPU executes this instruction, control is transferred to the monitor program, which allows the user to examine memory and registers for troubleshooting purposes.

VI. Conclusions

To conclude, the architecture, design, implementation and application of a microcomputer-based video pattern generator for use in ophthalmology has been presented. The system can be used by ophthalmologists, clinical psychologists, pediatricians and optometrists to efficiently diagnose many vision diseases and disorders especially among infants and noncommunicative people.

The system can be interfaced to any host computer using an RS-232C serial interface.The host would provide the necessary user interface to the system, which can be used to provide information on many parameters of the patterns such as the disparity of the stereopsis forms, movements of the form, selection of patterns, frequency of reversals of the checkerboards and bars, the size of the bars and checkerboards, etc. The system's software has been written using the TMS 34010 assembly language programming and Basic.The system is flexible, fast, and inexpensive with many features and options.

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References:

[1] O. Braddick and J. Atkinson," Some recent findings on the development of human binocularity: A review," Behavioral Brain Research, Vol. 10, PP.141-150, 1983.

[2] B. Julesz, " Foundation of Cyclopian Perception", The University of Chicago Press, Chicago, 1971.

[3] T. Tessman,"Perspectives on Stereo," SPIE - Stereoscopic Displays and Applications, Vol. 1256, pp. 22-27, 1990.

[4] B. Julesz and S. Johnson, "Mental Holography: Stereograms Portraying Ambiguously Perceivable Surfaces," *The Bell System Technical Journal*, Vol. 47, No. 10, pp. 2075-2093, December 1968.

[5] B. Julesz, "Binocular depth perception of computer-generated patterns," *The Bell System Technical Journal*, Vol. 39, No. 5, pp.1125-1162, September 1960.

[6] S. Wixson,"Volume Visualization on a Stereoscopic Display," *SPIE - Stereoscopic Displays and Applications*, Vol. 1256, pp. 110-112, 1990.

[7] M. Mizuno, S. Imami, M. Tsukada, E. Hida, and K. Nakak, "A Microcomputer System for Spatiotemporal Visual Receptive Filed Analysis," *IEEE Transactions on Biomedical Engineering*, Vol. BME-32, No. 1, pp. 56-60, January 1985.

[8] S.S. Shetty, A.J. Broderson, and R. Fox, "Generation of Random Element Stereograms in Real Time," *Behav. Res. Meth., and Inst.*, Vol. 111, pp. 485-490, 1979.

[9] M.S. Obaidat and L.E. Leguire, "A Dynamic and Static Microcomputer - Based Stereogram Generator," *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 21, No. 1, pp. 228- 231, January/February 1991.

[10]M.S. Obaidat and L.E. Leguire, "Architecture and Design of a Computerized Stereogram Generator for Vision Test," *Medical and Biological Engineering and Computing Journal*, Vol. 28, pp. 166-170, 1990.

[11]"TMS34010 User's Guide," Texas Instruments Inc., Texas, 1988.

Disp2	Disp1	Disp0	Delay (Pixels)
0	0	0	2
0	0	1	4
0	1	0	6
0	1	1	8
1	0	0	10
1	0	1	12
1	1	0	14
1	1	1	16

Table 1: Disparity levels.

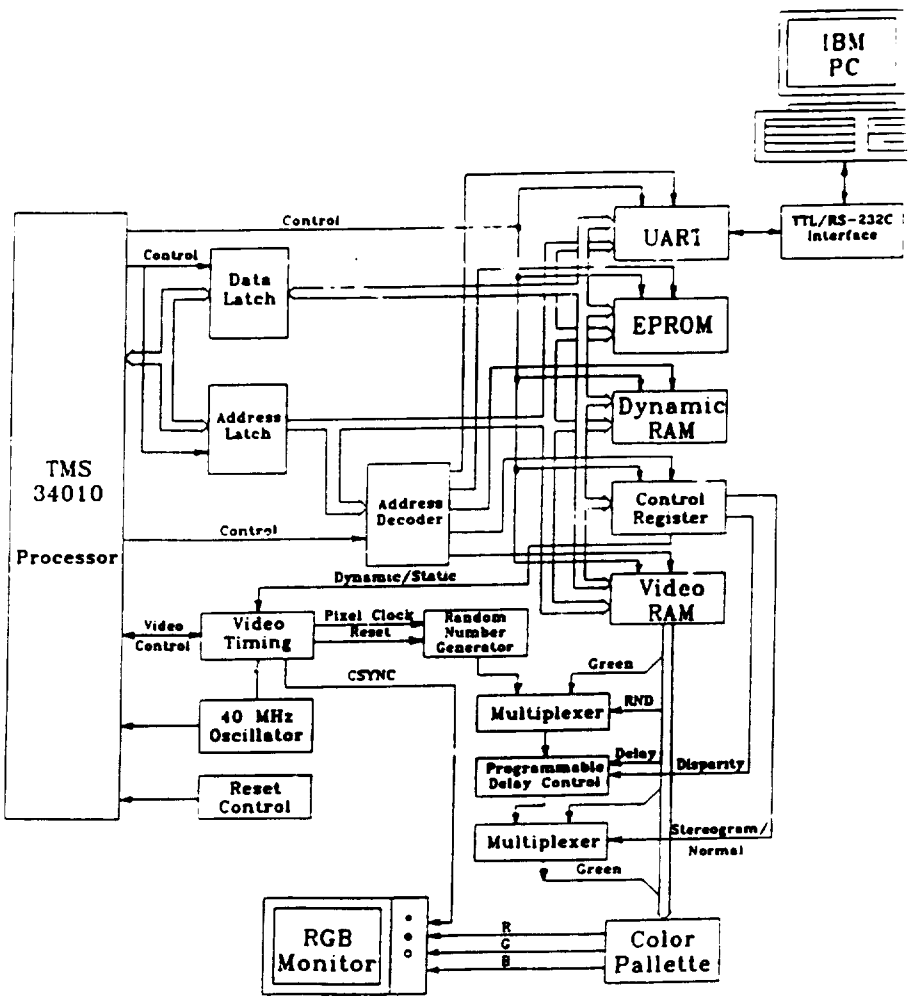

Figure 1: Block diagram of the video pattern generator system.

Bit 3	Bit 2	Bit 1	Bit 0
Delay Pixel	Random Pixel	Red	Green

Figure 2: Pixel definition format in the stereogram mode.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mode	Dynamic	N/F	N/F	N/F	Disp2	Disp1	Disp0

N/F : No Function, available for future expansion.

Figure 3: Bit definition of the control register.

Figure 4: One example of a static random dot stereogram portraying a rectangular stereoscopic form generated by the system.

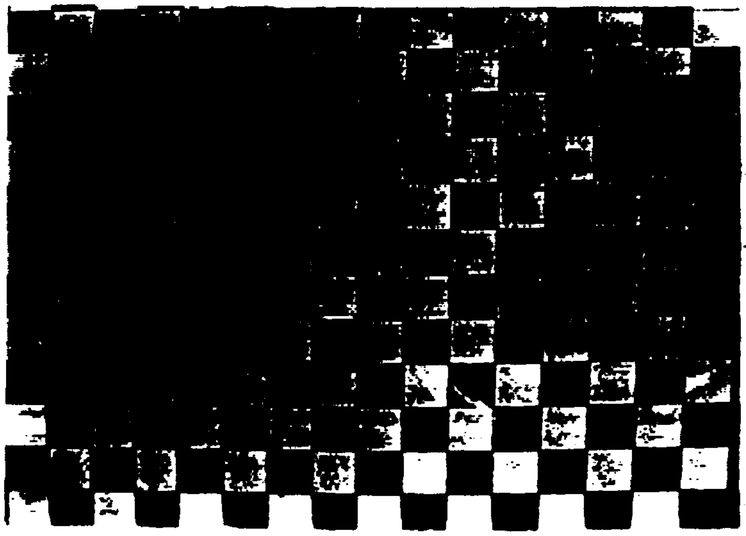

Figure 5: A checkerboard pattern generated by the system.

Figure 6: Vertical bars Pattern generated by the system.