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(71) Applicant: HONEYWELL INC.
Honeywell Plaza
Minneapolis Minnesota 55408(US)

(72) Inventor: Thompson, Eldon John
Route 1 Box 92M
Ruckersville Virginia 22968(US)

(74) Representative: Rentzsch, Heinz et al
Honeywell Europe S.A. Holding KG Patent & License Dept. Postfach 10 08 65
Kaiserleistrasse 39
D-6050 Offenbach am Main(DE)

(54) Display system for color image quantization.

(57) An apparatus for displaying video color images and minimizing buffer memory size quantizes a video image into a reduced number of corresponding color values. A lookup table (16) for driving a refresh buffer is encoded with a set of neighboring color values for transforming a three component color video signal to two-component format. The two-component signals are stored in a frame buffer (20) of reduced capacity sufficient to store the quantized color image. When addressed by a raster scan (21) the frame buffer is read out into a second lookup table (22) for converting the quantized image into a reduced set of color values. Since no intermediate computing or processing is required, the transformation is accomplished in real time, allowing contemporaneous color display while reducing buffer memory size demands.

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DISPLAY SYSTEM FOR COLOR IMAGE QUANTIZATION

BACKGROUND OF THE INVENTION

The invention relates to apparatus for displaying color images in digital maps, and more particularly to an apparatus for quantizing color images for use with a frame buffer display.

Raster scan systems which provide a bit-mapped memory for extracting graphic images in line-by-line and pixel-by-pixel format in synchronism with a timing signal are well known in the graphics display art. The video images are mapped into the display memory addresses in accordance with pixel locations on the face of the display. The raster lines are then recovered directly from the display memory by sequentially accessing the bytes stored therein, transferring them to a buffer, and feeding the output of the buffer to modulate the intensity of the corresponding pixel.

The display memory for a 512-by-512 pixel array must support over 250,000 pixel locations. The graphics controller is required to generate pixel color values at a rate commensurate with the resolution and frame refresh rate of the display. Typically, a monochromatic display for a 512-by-512 pixel array refreshed at 30 Hz must access data from memory and process the data to provide display signal amplitudes at a rate of about 8 million pixel values per second. Further, where there is a range of intensities and colors to be displayed, a multiple bit word is required to define the color state of each pixel. Since conventional memory arrays and shift registers can support the required serial addressing rates, only when each pixel value corresponds to a single bit, it has been found necessary to use multiple memory planes accessed in parallel, with a separate plane provided .for each bit. For a typical red-green-blue (R-G-B) video process, a minimum of 3 bits is required to define a single pixel value with a useful range of 8 color values for digital display mapping purposes. Thus, three parallel memory planes are required.

Moreover, when complex graphics are displayed, a significant time period can be required to create an image in memory. Since the scan is continuous in a raster display, an observer will see the image being printed in the screen as it is being loaded into the display buffer. In some applications this is unacceptable. Therefore, a technique of double-buffering has been employed, wherein two full-size buffers are provided. In operation, while the raster scan is displaying one buffer, the second is being updated. Once the image is complete, the buffers are alternated. This is a very effective technique used with frequency in graphics display systems. However, the penalty is, of course, double the required number of memory devices.

The present invention as defined in the independent claims provides an improved apparatus for displaying color images requiring multiple buffers and memory planes, while minimizing the image buffer size to that required by a pseudocolor diaplay system. A pseudocolor display system is defined as one on which video images may not need a full spectrum of colors, and therefore the number of colors and their respective intensity levels may be predefined. This is true, for example, with a digital map display, where the application of colors to define symbols and terrain features is well defined, as in conventional paper maps, or in image enhancement applications where it is desired to create a pseudocolor display of a monochromatic image. Preferred details of the invention are described in the dependent claims.

The invention includes a video generator for supplying full-spectrum color images in a plurality of displayable R-G-B color values, coupled to a lookup table, wherein are encoded in pseudocolor format a reduced number of color values corresponding to neighboring values of the full-spectrum display. The lookup table is so constructed that an address corresponding to any of the displayable color values will access the closet neighboring color in pseudocolor format. The table is addressed by the video source and the encoded color values stored in a frame buffer. When the buffer is filled, the output is sequentially applied to a decoder which converts the encoded word stored in the buffer to a displayable R-G-B color value. The invention will now be described with reference to the drawings, wherein

Figure 1a, Figure 1b, Figure 1c, and Figure 1d are block diagram representations of frame-buffer organization for monochrome, R-G-B and pseudocolor displays.

Figure 2 is a diagrammatic representation of the memory organization of a video lookup table of the present invention.

Figure 3a, Figure 3b, and Figure 3c show the development of a vector color state map in R-G-B format.

Figure 4 is a block diagram showing the frame buffer organization of the present invention.

Figure 5 is a schematic representation of the implementation of the color decoder of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As noted above, the size of the data word which describes the color value of each pixel is a key factor in determining the total memory size of the buffer. Since the number of bits of each data. word is multiplied by the X-Y pixel extent (e.g., 512 x 512 pixels), even a relatively small data word requires a substantial memory size.

By organizing the display memory into two or more duplicate sections or planes, the capabilities of a graphics system may be significantly expanded. Thus, the bits for each pixel in a bit-mapped memory may be accessed in parallel to form a multi-bit pixel word. The most general application for multiple memory planes is to create intermediate gray shades on a monochromatic display or multiple colors on a color display. Thus, as shown in Figure 1a, eight display memory planes will produce an 8-bit word that defines up to 256 shades of grey, which when applied to a digital-to-analog convertor (DAC) can be used to modulate the beam intensity of a cathode ray tube accordingly. Three planes, one assigned to each of the red, green, and blue primary colors, can generate eight colors, by mixing the primary color components. Similarly, two planes per color would permit generating four intensities per color, thus providing a total of 64 color values on the display face.

Two types of frame buffer pixel descriptor organizations have been employed in color raster displays. The first is an R-G-B (red, green, blue) format which describes the pixel in terms of the composition of additive color components. The same structure is useful for any three-component transform of a video image, such as hue-intensity-saturation (H-I-S) format. Figure 1c shows an R-G-B frame buffer memory organized as three groups of five memory planes. Thus, each group provides a 5-bit pixel descriptor to characterize a primary color component, and the 15-bit output thereby yields a spectrum of 32,768 colors, but requires a substantial memory capacity. While costs are falling rapidly for semiconductor memories, suitable high reliability components, particularly for military-grade applications, still pose significant problems of cost and size.

A second approach is a pseudocolor format, as shown in Figure ld. There is a frequent need, as in digital map displays, for both a relatively small number of colors in a picture or application and the ability to change colors from picture to picture or application to application. For this reason, the buffer-memory of raster displays may include a video lookup table. The value of a pixel is not routed directly to the display device, but is instead used to address a lookup table, which is an auxiliary memory programmed with a predetermined set of a reduced number of colors. The pixel address is used to control the color value of the display face. While the lookup table must have as many storage spaces as there are displayable pixels, it may characterize a reduced number of colors by a smaller pixel descriptor than is applied to address the table. Further, by using.a programmable memory (PROM), the table entries may be dynamically changed, for example, to expand a color range or reflect a change in application. Figure 1d shows a programmable pseudocolor display employing eight memory planes to generate an eight-bit pixel descriptor. The memory output is applied to a 256 entry lookup table which provides red, green, and blue color outputs of 5-bit word size. Note, by comparison with Figure 1c, that only 8 memory planes are required to produce 256 colors, a significant reduction from the 15 memory planes required by the R-G-B frame buffer, which, however, is capable of producing a vastly greater number of color combinations. The R-G-B system offers the greater flexibility while the pseudocolor system utilizes memory more efficiently. Since, for many video images, a palette of 256 colors is quite sufficient, the present invention provides an apparatus for accessing a lookup table encoded in pseudocolor format and providing an output in R-G-B format.

Encoding a pseudocolor lookup table requires quantization of the color values in a video image. It may be defined as the process of assigning representation values to ranges of input values (Heckbert, P., "Color Image Quantization for Frame Buffer Display", Association of Computing Machinery, V: 16, No. 3 (July 1982), 297- 307. Color image quantization is the process of selecting a set of colors to represent the color gamut of an image, and computing the mapping from color space to representative colors. Thus, many color images which would otherwise require a frame buffer having 15 bits per pixel can be quantized to 8 or fewer bits per pixel with little observable degradation.

The color quantization task may be broken into four phases:

1. Choosing a set of color characteristics, preferably in R-G-B format.
2. Mapping original colors in the video image to their nearest R-G-B neighbors in the color set to construct a lookup table.
3. Mapping colors in the original image to encoded pixel values in the quantized image.
4. Decoding the quantized image to reconstruct an R.G.B. image.

In a digital map display system, for example, both the number of colors and the saturation and intensity levels will be predetermined. Additionally, the application of the color to the terrain and characters is clearly defined and does not change. For example, water may be depicted as green, the sky as blue, and terrain elevations in prescribed color bands. Thus the display lookup table may be constructed from a dedicated color set. A fixed color set is a requirement for the use of the present invention.

Referring to Figure 2, a 256 word color set is defined to form a table. Column A represents the entry number from 0 to 255, column B the corresponding color reference number, and columns C, D, and E represent the corresponding red-green-blue color constituent of the desired color set in binary format. Each color combination corresponds to an arbitrary 8-bit hue-intensity descriptor. Three bits are used to identify a hue and provide 8 different hues (column F) and 5 bits to describe an intensity value of that hue providing 32 degrees of intensity shading (column G). An 8-bit buffer memory is assumed for this example, and a fixed value of saturation. A typical selection of corresponding colors is defined in column H. While the relationship between R-G-B and H-I-S descriptors is well known in the art and may be determined by mathematical relationships, as shown, for example, in "Raster Graphics Handbook", Conrac Corporation, Van Nostrand Reinhold Company, NY 2d Ed. 1985, 335-338, it is simpler to use an arbitrary 8 bit description, since the decoder may be programmed with a similar definition to regenerate the original R-G-B color values. Each 8-bit word corresponding to columns F and G defines a predetermined color value in terms of variable hue and intensity into which the 15 bit R-G-B video image is to be mapped. The color set defined must have all of the colors the system is required to generate. However, it is clear to one skilled in the art that by using a dynamically programmable memory for the lookup table, these values may be changed.

The R-G-B representation of the video image provides a total of 32,768 color combinations. Therefore, the encoder lookup table must be capable of being addressed by all 32,768 color commands. Thus, the encoder lookup table will be comprised of a 32K by 8 bit memory. Since, for example, a set of only 256 predetermined color values is stored in the encoder lookup table, in the form of 8-bit words describing hue and intensity, all addresses which do not expressly correspond to one of the predetermined colors will be assigned to one of 256 colors, based on the nearest color neighbor, as described below.

Referring now to Figures 3a, 3b, and 3c, the concept for mapping of 32,768 color states into 256 color states is illustrated. As noted above, the red-green-blue video representation provided 32,768 color states. Figure 3a shows a conceptual linear model of the color space, treating R, G, and B as vectors, and the origin O as white. While in practice equal components of the primary color components will not result in white, the model is adequate to illustrate the principles of the invention. In Figure 3b there is shown a plurality of dots, each dot representing one of the 32,768 color states available for a 5-bit R-G-B descriptor. In Figure 3c the small circles are representative of selected colors in a defined 256 state color set. Adjoining each of the 256 color states is a group of neighboring color states comprising the totality of 32,768 color states of Figure 4b.

The process of determining the nearest neighbor mapping need be computed only once for a particular application. The resulting values are then stored in the lookup table, which can be accessed at video rates to provide real time displays. The nearest neighbor is determined by a simple computation:

$d = (R_x-r_y)^2 + (G_x-g_y)^2 + (B_x-b_y)^2$

where:

r_y, g_y, b_y are the color values in decimal form created from the combination of each of the 5-bit r-g-b color states represented in Figure 3b.

R_x, G_x, B_x are the predetermined values in the color set of 256 colors.

d is the color "distance" to be minimized.

The 5-bit r-g-b color states are applied to address the lookup table. At each storage location, an 8-bit word is encoded with a hue and intensity value equivalent to one of the 256 R-G-B color states. For each value of R_x, G_x, B_x in the color set and the r_y, g_y, b_y color value accessed, a value of d is computed. Thus, a family of 256 values of d is solved, from which the minimum "d" is selected for the table to correspond to the PROM address of r_y, g_y, b_y. Once all the combinations of color states have been compiled and the values of d computed, the results may be tabulated so that each of the 256 color states is representative of a plurality of neighboring color states for which d is minimized. The lookup table is then encoded with these values. In operation, when the lookup table is addressed by a 15-bit r,g,b output of the video source, the nearest 8-bit value in the defined color set R,G,B will be accessed, without intermediate computations or processing.

Referring now to Figure 4, the relationship of the frame buffer to a lookup table encoder and decoder is shown. A video image 10 in digital form is applied to transform 12 to a generate a 15-bit color signal. The signal is preferably in R-G-B format, although it may also be transformed to hue, intensity and saturation (H-I-S) values. A system using a 5 bit color descriptor provides 32 different color values for each primary color, although this is exemplary, and not to be construed as limiting. A lookup table is encoded in programmable memory 16, which may be a 32K x 8 PROM, such as type 27256 UV erasable PROM, manufactured by Intel Corporation. Lookup table 16 is addressed by the 15-bit output and provides an 8-bit word corresponding to the color value of the nearest neighbor in the 256 word color set to a frame buffer 20. When the frame buffer is loaded, the stored values are extracted by the raster scan electronics (not shown) and applied to a further lookup table 22, which decomposes the encoded format back to the R-G-B color components to drive the display.

Figure 5 shows the circuit for decoding the 8-bit output of the frame buffer for driving the red, green, and blue exciting elements of a display; for example, the electron guns of a cathode ray tube. The frame buffer 40 feeds via an 8-bit bus 46 a latch 42, which stores the 8-bit color word and addresses a 256 x 15 lookup table 44. Table 44 may be comprised of three 5-bit x 256 word sections. Each section corresponds to one of the R-G-B color components of the 256 value color set. Table 44 is encoded identically with the color set of Figure 2, columns C, D, E and addressed in accordance with column F and G thereof. Thus, for each of the 256 combinations of hue and intensity represented by the 8-bit address on bus 46, a location will be selected in lookup table 44 that provides the corresponding quantized red, green, and blue color components of the encoded video image. The digital outputs of table 44 are applied to digital-to-analog convertors 48, 50, and 52, which convert the respective 5 digit inputs to one of 32 analog levels for modulating a corresponding color gun or pixel color value.

The lookup table generator 54 optionally permits reprogramming table 44 by gating out the signals from frame buffer 40 and applying a revised data table via data bus 56.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes may be made within the purview of the appended claims without departing from the true scope and spirit of the invention in its broader aspects.

Claims

1. A display system for quantization of color images, **characterized by** :

a) video generator means (10) for providing a substantially full-spectrum color image in digital form, said color image comprised of a plurality of displayable picture elements, each of said picture elements defining at least one color value of said color image,

b) means(16) for mapping substantially in real time a plurality of displayable color values to a plurality of encoded color values, single values of said plurality of encoded color values representative of a multiplicity of values of said plurality of displayable color values, wherein said encoded values are selected from a predetermined set of color values independent of the population density of said plurality of displayable color values, and said multiplicity is comprised of color values representative of the nearest neighbor to respective ones of said plurality of encoded color values, said nearest neighbor determined by minimizing the difference of said displayable color values and said encoded color values,

c) means (12) responsive to said video generator means for sequentially applying signals corresponding to the color values of said picture elements to said mapping means and for deriving signals corresponding to ones of said plurality of encoded color values,

d) digital storage means (20) having a plurality of addressable storage locations for receiving said encoded color values, each of said storage locations corresponding to one of said picture elements and to one of said encoded color values,

e) means (21) for sequentially addressing said digital storage means and deriving the encoded color values corresponding to said picture elements, and

f) decoder means (22), responsive to the application of said derived encoded color values. for transforming said applied encoder color values to corresponding predetermined displayable color values substantially in real time.

2. A display system according to claim 1, **characterized in that** said displayable color values are in Red-Green-Blue format.

3. A display system according to claim 1 or 2, **characterized in that** said encoded color values are in Hue, Intensity, Saturation format.

4. A display system according to claim 1, 2 or 3, **characterized in that** said mapping means (16) is arranged to provide 256 encoded colors corresponding to 32 768 displayable colors.

5. A display system according to one of the preceding claims, **characterized in that** said mapping means comprises a lookup table (16) and said table is addressed by a digital signal corresponding to one of said displayable color values and provides an output corresponding to one of said encoded color values, and said corresponding en-

coded color value is determined by minimizing squares of sums and differences of said displayable color values and said encoded color values.

6. A display system for quantization of color images, **characterized by**

a) means for storing a plurality of digital words corresponding to predetermined color values in a first look-up table (16), said table when addressed by a three-component digital signal (12) providing a corresponding two-component digital signal representative of one of said plurality of digital words corresponding to predetermined color values.

b) means (14) for sequentially applying video signals in digital form to said first look-up table, said signals corresponding to a color picture image in three-component format,

c) means (18) for sequentially deriving two-component digital signals representative of said picture image from said first look-up table, said two-component signals independent of the statistical frequency distribution of the color values of said picture image, each of said two-component signals selected for display from the nearest neighbor of said three-component signals in accordance with the relationship

$$d = (R_x-r_y)^2 + (G_x-g_y)^2 + (B_x-b_y)^2$$

where d is a parameter having a minimum value,

d) buffer memory means (20) for storing and retrieving said two component digital signals,

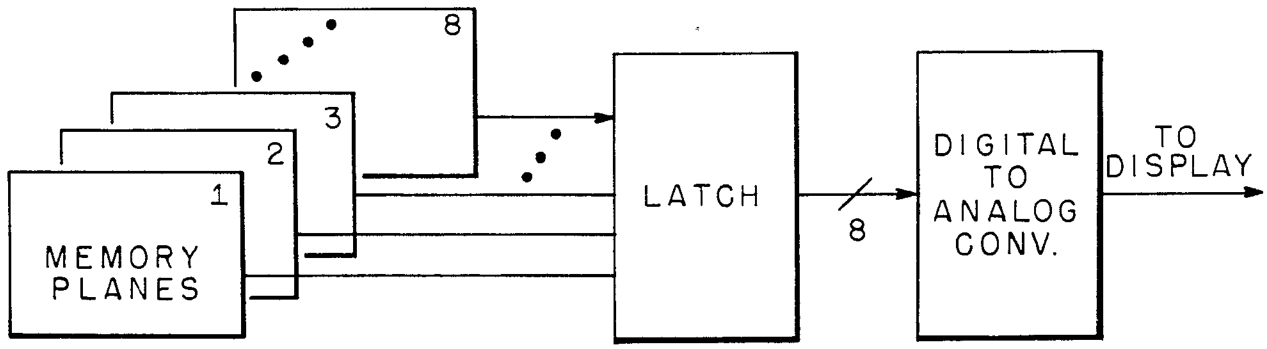
e) second look-up table means (22) coupled to receive said two component signals from said buffer memory means, said second look-up table means so constructed and arranged as to generate three-component digital signals corresponding to said received two-component signals, and

f) means (48,50,52) for applying said generated three-component signals for energizing corresponding control elements of a display means, thereby to substantially reconstruct said color picture image.

7. A display system according to claim 6, **characterized in that** said first lookup table (16) is derived by constructing a matrix of digital words corresponding to color values neighboring a predetermined set of color values, said neighboring color values derived from minimizing sums of differences and squares of color values corresponding to said plurality of color values and said predetermined set of color values.

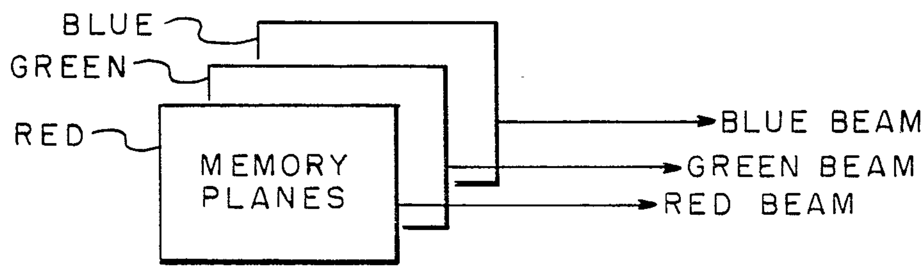
8. A display system according to claim 6 or 7, **characterized in that** said three-component signal comprises red, green, and blue primary spectral components of an R-G-B system.

9. A display system according to one of the claims 6 to 8, **characterized in that** said two-component signal comprises hue and intensity components of an H-I-S system.



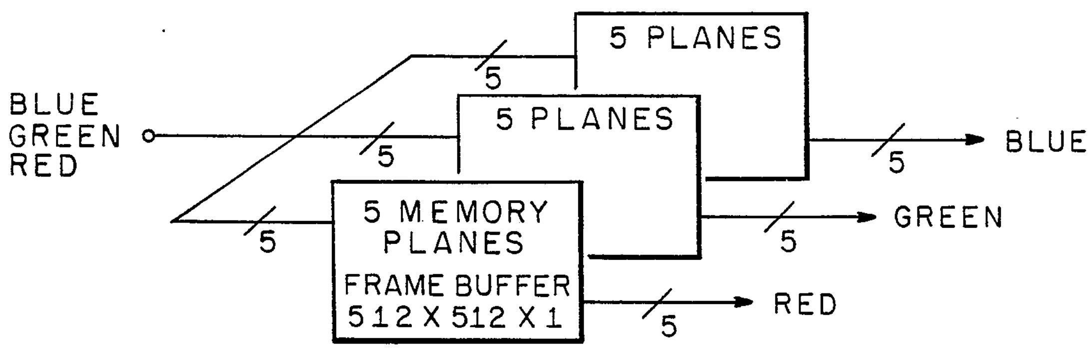
MONOCHROME DISPLAY MEMORY

FIG.1a.



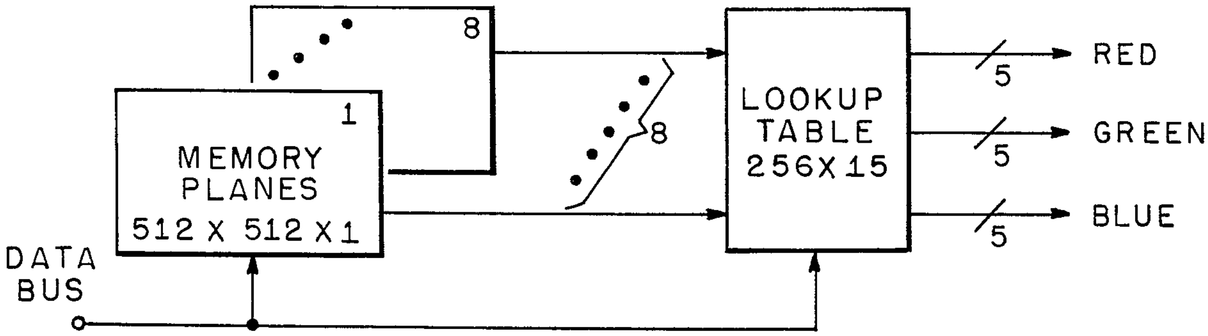
8-COLOR DISPLAY MEMORY

FIG.1b.



R-G-B FRAME BUFFER

FIG.1c.



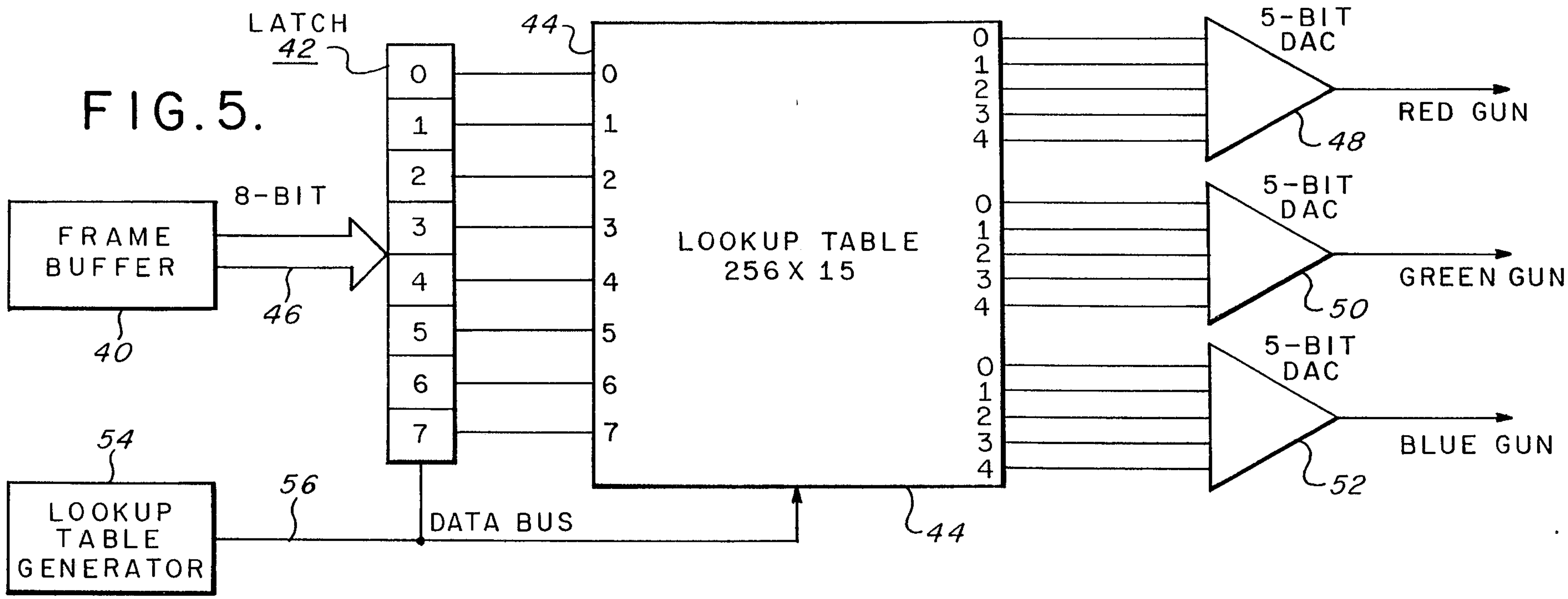
PROGRAMMABLE PSEUDOCOLOR DISPLAY

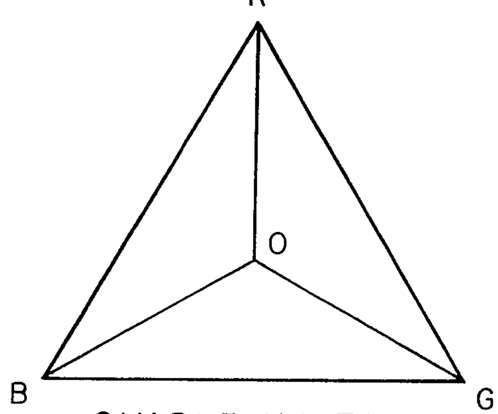
FIG.1d.

TABLE ENTRY	COLOR NO.	5-BIT COLOR DEFINITION			8-BIT COLOR DEF.		VISIBLE COLOR
		RED	GREEN	BLUE	HUE	INTENSITY	
0	1	11111	00000	00000	000	00000	BRIGHT RED
1	2	11000	00000	00000	000	00001	MEDIUM RED
2	3	00111	00000	00000	000	00010	DIM RED
3	4	00000	00000	11111	000	00011	BRIGHT BLUE
4	5	00000	00000	11000	000	00100	MEDIUM BLUE
5	6	00000	00000	00111	000	00101	DIM BLUE
.	.						
.	.						
.	.						
255	256						
A	B	C	D	E	F	G	H

FIG.2.

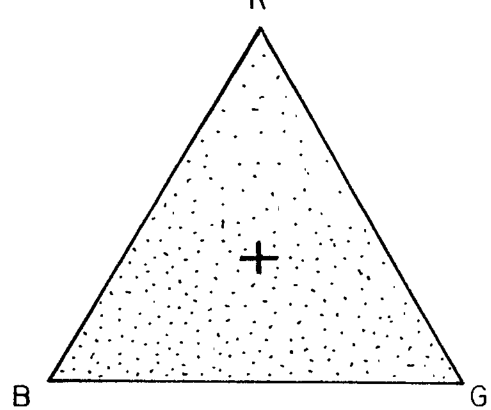
FIG.5.





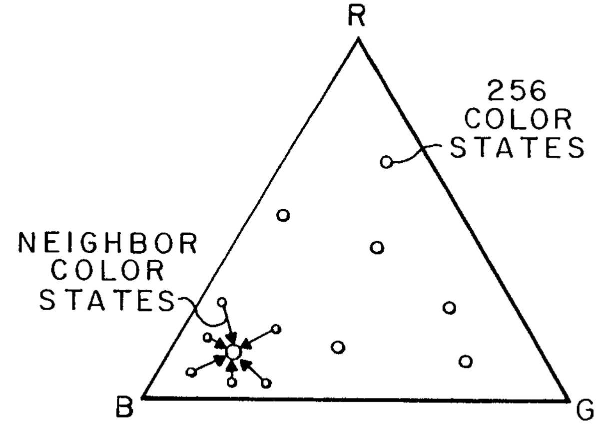
SIMPLE VECTOR
COLOR SPACE MODEL

FIG.3a.



32,768 COLOR STATES
FOR 5-BIT R-G-B

FIG.3b.



NEAREST NEIGHBOR
MAPPING IN COLOR SPACE

FIG.3c.

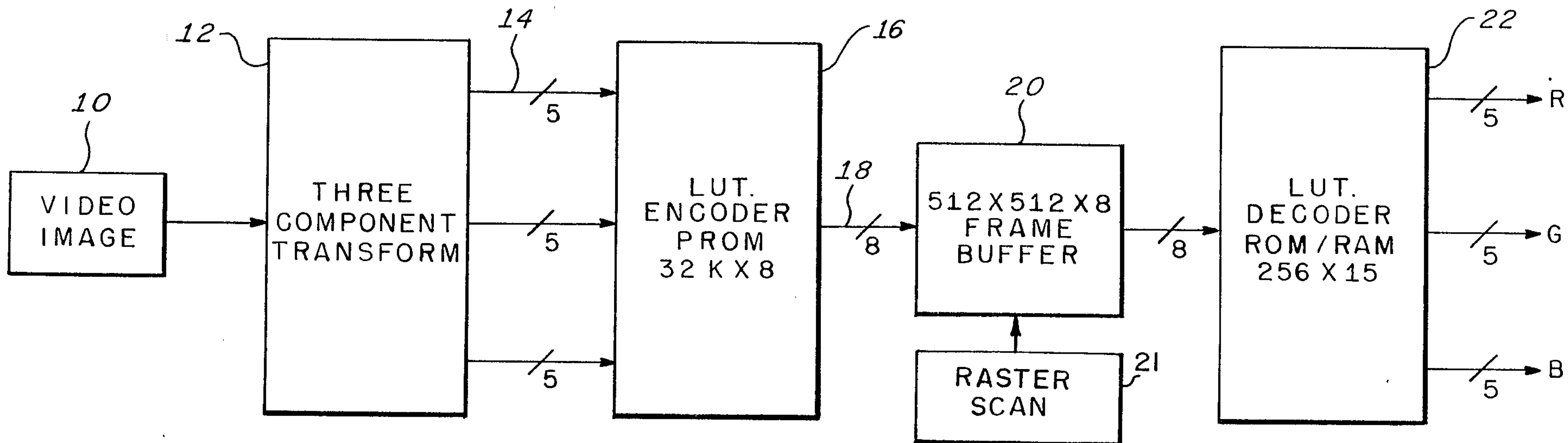


FIG.4.