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(54) Graphical image intensity rescaling mechanism

(57) In a computer graphics system which includes a frame buffer which in turn performs a depth cue display, a graphical image is displayed by (i) representing the graphical image in a Z buffer of the frame buffer such that the display intensity corresponding to a numerical value of each pixel is represented as the Z coordinate of the pixel and (ii) invoking the depth cue display. Thus, by operation of the depth cue mechanism, pixels associated with a particularly high numerical value have a particularly high Z coordinate and are therefore represented with a particularly high intensity. Similarly, pixels associated with a particularly low numerical value have a particularly low Z coordinate and are therefore represented with a particularly low intensity. As a result, the graphical image is represented as a greyscale graphical image. In addition, the relationship between specific Z coordinate values and respective display intensities is controlled by the frame buffer according to data stored within the frame buffer, e.g., in a number of registers of the frame buffer. To change the scaling of the greyscale graphical image as displayed, new data are written to the frame buffer and the frame buffer is directed to redisplay the graphical image from the Z buffer according to the new relationship represented by the new data stored in the frame buffer. Accordingly, the general-purpose processor of such a computer system has very little involvement in the rescaling of the graphical image. Instead, the frame buffer retrieves pixel records from the Z buffer, processes the pixel records according to the new data, and writes colors determined by processing the pixels records to a refresh buffer for display in a computer display device. As a result, the general purpose processor is free to handle other tasks with minimal interruption. In addition, the frame buffer typically includes a video processor which is specifically designed to process pixel records of a Z buffer in a particularly efficient manner and therefore rescales the graphical image very efficiently and quickly.

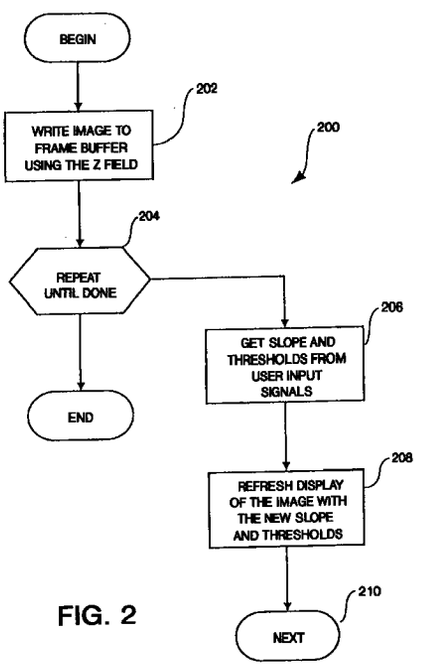


FIG. 2

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Description

FIELD OF THE INVENTION

The present invention relates to graphical image processing in a computer system and, in particular, to a particularly efficient mechanism for rescaling a graphical image.

BACKGROUND OF THE INVENTION

Rescaling a graphical image generally refers to multiplying a numerical value associated with each pixel of the graphical image by a scalar coefficient and can include adding or subtracting a constant to the numerical value associated with each pixel. In some graphical images, each pixel represents a numerical value associated with a datum. For example, graphical images are frequently used to represent X-ray or computerized axial tomography (CAT) scan images using a computer display device. In addition, graphical images are frequently used to represent seismic signals, e.g., seismic lines which include multiple seismic traces, each of which is represented by a column of pixels. In such graphical images, each pixel represents a digital sample of a seismic signal of a trace. In these graphical images, each pixel is associated with a numerical value corresponding to a discrete sample of signal. In the case of a graphical image of an X-ray, each pixel is associated with a numerical value representing the density of biological tissue at a particular point as measured by an X-ray machine. In the case of a graphical image representing a seismic signal, each pixel is associated with a numerical value representing the amplitude at a particular time of a vibration recording using a geophone.

In displaying such graphical images, a color is associated with each possible numerical value associated with a pixel. Such graphical images are frequently represented as a greyscale image in which all pixels have generally the same hue but vary in intensity according to the numerical value of each pixel. However, much of the subtlety of the data represented by such a greyscale graphical image is lost since the human eye can only perceive a limited number variations in intensity in a color when hue remains constant. For example, the average human eye can perceive only a very few distinct gradations of grey between black and white, i.e., typically no more than sixteen distinct gradations of grey. On the other hand, it is common for a greyscale graphical image representing a grid of numerical values, such as an X-ray image or a seismic signal, to have 256 or more distinct gradations of grey.

Rescaling such a graphical image in accordance with control signals generated by a user, e.g., by physical manipulation of a pointing device, places the greatest contrast in pixel colors or intensity at any area of interest. For example, by quadrupling the numerical value associated with each pixel of an X-ray image whose pixels range from 0 to 255, all pixels associated with a numerical value in the range of 64 to 255 are displayed with the color associated with the value 255 and pixels associated with a numerical value in the range of 0 to 63 are displayed using the full spectrum of grey intensities. As a result, pixels associated with numerical values in the range of 0 to 63 are displayed with more clarity and detail and pixels associated with numerical values in the range of 64 to 255 are displayed in one color and are therefore indistinguishable from one another. The user can therefore "focus" the available contrast in the graphical image to a particular range of interest. In addition, if the "focused" numerical range can be shifted in accordance with control signals, e.g., generated by physically manipulation of a pointing device, the user can observe and perceive particularly subtle features of the graphical image by moving the high contrast range back and forth over a range of interest. By quickly rescaling and redisplaying the graphical image with incremental changes in the scaling of the numerical values associated with the pixels of the graphical image, the graphical image takes on a quality suggestive of motion which emphasizes further subtle features in the graphical image.

Rescaling a graphical image requires substantial computer processing resources. For example, a graphical image having one thousand columns and one thousand rows of pixels requires at least one million multiplication operations, one million addition or subtraction operations, and two million threshold operations, e.g., to ensure that each pixel has a value in a range of valid values. The results of the four million operations must generally be written to a frame buffer for display on a computer display device. In addition, to provide a quality suggestive of motion as described above, such rescaling must generally be accomplished twenty times per second and preferably at least 30 times per second. The processing demands of a computer system which rescales a graphical image in the described maker do not end with the rescaling of the graphical image since the processor is typically also responsible for carrying out other operations such as managing user input devices which generate control signals to control the rescaling of the graphical image and perhaps other components of a graphical user interface (GUI). In other words, a dedicated computer processor is typically not available for performing the rescaling described above.

Accordingly, a need persists in the industry for a particularly efficient rescaling mechanism whereby a graphical image can be more quickly rescaled while simultaneously reducing the operational burden of a processor of a computer system.

SUMMARY OF THE INVENTION

Some computer graphics systems include a frame buffer which performs some image processing func-

tions, including a depth cue mechanism. In a depth cue, pixels are defined in a three dimensional view space in which the Z axis is normal to the viewing surface and pixels which are nearer the viewer as determined by the Z coordinate of the pixel are displayed with greater intensity. In accordance with the present invention, a graphical image is represented in a Z buffer of such a frame buffer such that the Z coordinate of each pixel represents the numerical value associated with each pixel. Thus, by operation of the depth cue mechanism pixels associated with a particularly high numerical value have a particularly high Z coordinate and are therefore represented with a particularly low intensity. Similarly, pixels associated with a particularly low numerical value have a particularly low Z coordinate and are therefore represented with a particularly high intensity. As a result, the graphical image is represented as a greyscale graphical image.

In addition, the relationship between specific Z coordinate values and respective display intensities is controlled by the frame buffer according to data stored within the frame buffer, e.g., in a number of registers of the frame buffer. To change the scaling of the greyscale graphical image as displayed, new data are written to the frame buffer and the frame buffer is directed to redisplay the graphical image from the Z buffer according to the new relationship represented by the new data stored in the frame buffer. Accordingly, the general purpose processor of such a computer system has very little involvement in the rescaling of the graphical image. Instead, the frame buffer retrieves pixel records from the Z buffer, processes the pixel records according to the new data, and writes colors determined by processing the pixels records to a refresh buffer for display in a computer display device. As a result, the general purpose processor is free to handle other tasks with minimal interruption. In addition, the frame buffer typically includes a video processor which is specifically designed to process pixel records of a Z buffer in a particularly efficient manner and therefore rescales the graphical image very efficiently and quickly.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a computer system which includes an image processor which rescales graphical image data within a frame buffer in accordance with the present invention.

Figure 2 is a logic flow diagram illustrating the rescaling of graphical image data by the image processor of Figure 1 in accordance with the present invention.

Figure 3 is a logic flow diagram of a step of the logic flow diagram of Figure 2.

Figure 4 is a block diagram showing the frame buffer of Figure 1 in greater detail.

Figure 5 is a block diagram of a pixel record of a Z buffer of the frame buffer of Figure 4.

Figure 6 is a block diagram of registers of the frame buffer of Figure 4.

Figure 7 is a diagram illustrating a relationship between pixel intensity and Z coordinates.

DETAILED DESCRIPTION

Some computer graphics systems include a frame buffer, e.g., frame buffer 120 (Figure 4), which performs some image processing functions, including a depth cue mechanism. In a depth cue, pixels are defined in a three dimensional view space in which the Z axis is normal to the viewing surface and pixels which are nearer the viewer as determined by the Z coordinate of the pixel are displayed with greater intensity. In accordance with the present invention, a graphical image is represented in a Z buffer 404 of frame buffer 120 such that the Z coordinate of each pixel represents the numerical value associated with each pixel. Thus, by operation of the depth cue mechanism pixels associated with a particularly high numerical value have a particularly high *Z* coordinate and are therefore represented with a particularly low intensity. Similarly, pixels associated with a particularly low numerical value have a particularly low Z coordinate and are therefore represented with a particularly high intensity. As a result, the graphical image is represented as a greyscale graphical image.

In addition, the relationship between specific Z coordinate values and respective display intensities is controlled by frame buffer 120 according to data stored in a number of registers 408. To change the scaling of the greyscale graphical image as displayed, new data are written to registers 408 and frame buffer 120 is directed to redisplay the graphical image from Z buffer 404 according to the new data stored in registers 408. Accordingly, the general purpose processor of the computer system, e.g., processor 102 (Figure 1), has very little involvement in the rescaling of the graphical image. Instead, frame buffer 120 (Figure 4) retrieves pixel records from Z buffer 404, processes the pixel records according to the new data stored in registers 408, and writes colors determined by processing the pixels records to a refresh buffer 206 for display in a computer display device, e.g., computer display device 122 (Figure 1). As a result, processor 102 is free to handle other tasks with minimal interruption. In addition, video processor 402 (Figure 4) of frame buffer 120 is typically specifically designed to process pixel records of Z buffer 404 in a particularly efficient manner and therefore rescales the graphical image very efficiently and quickly.

Hardware Components of the Image Processing System

To facilitate appreciation of the present invention, the hardware components of the rescaling system are briefly described. Computer system 100 (Figure 1) includes a processor 102 and memory 104 which is coupled to processor 102 through a bus 106. Processor

102 fetches from memory 104 computer instructions and executes the fetched computer instructions. Processor 102 also reads data from and writes data to memory 104 and sends data and control signals through bus 106 to one or more computer display devices 120 in accordance with fetched and executed computer instructions.

Memory 104 can include any type of computer memory and can include, without limitation, randomly accessible memory (RAM), read-only memory (ROM), and storage devices which include storage media such as magnetic and/or optical disks. Memory 104 includes an image processor 110, which is a computer process executing within processor 102 from memory 104. A computer process is a collection of computer instructions and data which collectively define a task performed by computer system 100. As described more completely below, image processor 110 (i) reads pixels from image buffer 112 and writes them to frame buffer 120, (ii) writes to registers 408 (Figure 4) of frame buffer 120 data representing a particular relationship between pixel values and intensity, and (iii) causes frame buffer 120 to display the pixels from image buffer 112 (Figure 1) according to the particular relationship. Processing by image processor 102 is described more completely below with respect to logic flow diagram 200 (Figure 2).

Processor 102 (Figure 1) also receives signals through bus 106 from user input devices 120 which can include, without limitation, a keyboard, a numeric keypad, and/or a pointing device such as an electronic mouse, lightpen, trackball, digitizing tablet, or thumbwheels. In response to physical manipulation by a user, user input devices 120 generate signals representing such physical manipulation and send such signals through bus 106 to processor 102. The generation of signals by user input devices 120 in response to physical manipulation by a user and the receipt of such signals by processor 102 are well-known and conventional.

Computer system 100 also includes a frame buffer 120 which includes memory and logic for displaying graphical images on a computer display device 122. Computer display device 122 can be any type of computer display device including, for example, a cathode ray tube (CRT), a light-emitting diode (LED) display, or a liquid crystal display (LCD). Frame buffer 120 receives data and control signals from processor 102 through bus 106 and processes the data to form graphical images in accordance with the control signals. In addition, frame buffer 120 sends to processor 102 through bus 106 data representing the state of frame buffer 120 in response to control signals so directing. Frame buffer 120 is conventional and provides a conventional depth cue mechanism.

Interactive Rescaling of a Graphical Image

As described above, image processor 110 rescales a graphical image in accordance with control signals generated by user input devices 120 in response to physical manipulation by a user. The processing of image processor 110 is illustrated in logic flow diagram 200 (Figure 2) and begins in step 202. In step 202, image processor 110 (Figure 1) retrieves pixel data from image buffer 112 and causes frame buffer 120 to display a graphical image in accordance with the pixel data in computer display device 122. Image processor 110 causes display of the graphical image by sending the pixel data and control signals through bus 106 to frame buffer 120. In step 202 (Figure 2), image processor 110 (Figure 1) causes frame buffer 120 to display the graphical image as a greyscale graphical image by storing the numerical value associated with each pixel as a corresponding Z field of a pixel field in Z buffer 404 (Figure 4) and invoking a depth cue display by operation of the depth cue mechanism of frame buffer 120. Frame buffer 120 is shown in greater detail in Figure 4.

Frame buffer 120 includes video processor 402, Z buffer 404, and refresh buffer 406. The image displayed by computer display device 122 (Figure 1) is repeatedly retrieved from refresh buffer 406 (Figure 4). Accordingly, the contents of refresh buffer 406 define the display of computer display device 122 (Figure 1), and video processor 402 (Figure 4) controls the display of computer display device 122 by writing data to refresh buffer 406. Z buffer 404 is a memory buffer which is used by video processor 402 as a workspace for creating graphical images for display through refresh buffer 406. For example, video processor 402 can use Z buffer 404 to implement hidden surface removal and depth cue displays in a conventional manner. Z buffer 404 includes a number of pixel records, such as pixel record 502 (Figure 5), and generally includes a pixel record for each pixel displayed in computer display device 122.

Pixel record 502 (Figure 5) includes a Y field 504, a Z field 506, an alpha field 508, a blue field 510, a green field 512, and a red 514. As used herein, a field is a collection of data which collectively specify is unitary piece of information. Alpha field 508, blue field 510, green field 512, and red field 514 collectively define a color in alpha, blue, green, and red format. Z field 506 represents a Z coordinate in a three-dimensional display space and is used, for example, in depth cue display processing and in hidden surface removal. In step 202 (Figure 2), image processor 110 (Figure 1) sends to frame buffer 120 (Figure 4) control signals which direct video processor 402 to store in alpha field 508 (Figure 5), blue field 510, green field 512, and red field 514 data which collectively define a specific color which is stored, for example, in one of registers 408 (Figure 4). Registers 408 (Figure 6) include a color field 612, and, in writing pixel records from data of image buffer 112 (Figure 1), video processor 402 (Figure 4) copies the data from color field 612 (Figure 6) to alpha field 508, blue field 510, green field 512, and red field 514. As a result, the graphical image representing the pixel data of image

buffer 112 is displayed using the same color for each pixel. In one embodiment, the color represented by color field 612 (Figure 6) is white.

Therefore, the entire graphical image is displayed in varying intensities of white. Since the depth cue display of frame buffer 120 is invoked by image processor 110, the particular intensity of the color for a given pixel is determined by the Z coordinate of the pixel. In writing pixel data to frame buffer 120, image processor 110 directs video processor 402 (Figure 4) to store as Z field 506 (Figure 5) the numerical value of each pixel from image buffer 112 (Figure 1). Accordingly, each pixel has the same color but has an intensity which is determined by the value of the pixel as represented within image buffer 112 (Figure 1). Thus, by operation of the depth cue display performed by frame buffer 120, image buffer 112 is represented in computer display device 122 as a greyscale graphical image. After step 202 (Figure 2), Z buffer 404 (Figure 4) contains data representing the graphical image represented by image buffer 112 (Figure 1). Specifically, pixel data stored in image buffer 112 is replicated in the Z fields of pixel records of Z buffer 404 (Figure 4).

Processing transfers from step 202 (Figure 2) to loop step 204. Loop step 204 and next step 210 define a loop in which image processor 110 (Figure 1) rescales the graphical image displayed in step 202 according to steps 206-208. In step 206, image processor 110 (Figure 1) determines, in accordance with user input signals, parameters which collectively define a relationship between Z coordinates represented within Z buffer 404 (Figure 4) and intensities with which the pixels are displayed in computer display device 122 (Figure 1). Diagram 700 (Figure 7) illustrates a relationship between Z coordinates and intensity.

In diagram 700, the horizontal axis represents various Z coordinates in a range from 0.0 to 1.0. Of course, it is appreciated that in many implementations of Z buffer 404 store Z coordinates having a range which is different than the range from 0.0 to 1.0; however, scaling from one range to another can be accomplished using well-known and conventional techniques. In diagram 700, the vertical axis represents various pixel intensities in a range from 0.0 to 1.0. Other ranges can be used and scaling from one range to another can be accomplished using well-known and conventional techniques.

Curve 702 shows the relationship between Z coordinates and intensity. Curve 702 includes a line segment 702A which shows intensity clamped at an intensity minimum 704. Accordingly, pixels having a Z coordinate less than or equal to a Z minimum 708 are displayed with an intensity of intensity minimum 704. Curve 702 also includes a line segment 702C which shows intensity clamped at an intensity maximum 706. Thus, pixels having a Z coordinate greater than or equal a Z maximum 710 are displayed with an intensity of intensity maximum 706. Between line segments 702A and 702C, curve 702 includes a line segment 702B whose slope defines a linear relationship between (i) Z coordinates between Z minimum 708 and Z maximum 710 and (ii) intensities between intensity minimum 704 and intensity maximum 706. While curve 702 is shown as including line segments and defining linear relationships, curve 702 can include non-linear relationships to the degree frame buffer supports such non-linear relationships.

In addition, curve 702 represents a relationship in which greater Z values are associated with greater intensities. In one embodiment, frame buffer 120 only supports inverse relationships between Z values and intensity. In such an embodiment, values associated with each pixel are inverted prior to storing the numerical value as Z values. For example, pixel values which range from 0.0 to 1.0 are subtracted from 1.0 and the difference is stored as the corresponding Z value in one embodiment. As a result, a particularly high pixel value is represented by a particularly low Z value and a correspondingly particularly high intensity. Conversely, a particularly low pixel value is represented by a particularly high Z value and a correspondingly particularly low intensity.

In step 206 (Figure 2), a user specifies a change in the relationship represented by curve 702 (Figure 7) using conventional user-interface techniques. For example, a user can specify a new Z maximum 710 by entering a numerical value for Z maximum 710 using a keyboard or a numeric keypad. Alternatively, a user can specify a new slope of line segment 702B by manipulation of a virtual slider tool of a graphical user interface. Alternatively, diagram 700 is represented graphically in a computer display device, e.g., in a partitioned portion of computer display device 122 or in another computer display device, and the user can manipulate curve 702 directly using conventional drag-and-drop graphical user interface techniques.

Processing transfers from step 206 (Figure 2) to step 208. In step 208, image processor 110 (Figure 1) refreshes the display of the graphical image of image buffer 112 as represented in Z buffer 404 (Figure 4) in accordance with the new relationship between Z coordinates and intensity as specified by the user in step 206 (Figure 2). Step 208 is shown in greater detail as logic flow diagram 208 (Figure 3) in which processing begins in step 302.

In step 302, image processor 110 (Figure 1) writes to a slope field 602 (Figure 6) of registers 408 of video processor 402 (Figure 4) data representing a new slope of line segment 702B (Figure 7) as specified by the user. Processing transfers to step 304 (Figure 3) in which image processor 110 (Figure 1) writes to an intensity maximum field 604 (Figure 6) and an intensity minimum field 606 data representing new values for intensity maximum 706 (Figure 7) and intensity minimum 704, respectively, as specified by the user. In step 306 (Figure 3), to which processing transfers from step 304, image processor 110 (Figure 1) writes to a Z max-

imum field 608 (Figure 6) and a Z minimum field 610 data representing new values for Z maximum 710 (Figure 7) and Z minimum 708, respectively, as specified by the user.

Processing transfers from step 306 (Figure 3) to step 308. In step 308, image processor 110 (Figure 1) directs frame buffer 120 to redisplay the contents of Z buffer 404 (Figure 4). In response, video processor 402 (i) retrieves pixel records, e.g., pixel record 502 (Figure 5), from Z buffer 404 (Figure 4); (ii) assigns a color to each pixel having an intensity determined in accordance with the Z coordinate of each pixel and with curve 702 (Figure 7) as specified by registers 408 (Figure 4) by operation of a depth cue display; and (iv) writes data representing the assigned color of each pixel to refresh buffer 406, thereby causing display of the assigned color of each pixel to computer display device 122. After step 308 (Figure 3), processing according to logic flow diagram 208, and therefore step 208 (Figure 2), completes. Thus, the rescaling of the graphical image in accordance with control signals generated by the user is performed substantially entirely within frame buffer 120 (Figure 1). Regardless of the size of the graphical image represented by image buffer 112, involvement of processor 102 in the rescale and redisplay of the graphical image is generally limited to writing a relatively small amount of data to registers 408 (Figure 4) and relatively few control signals directing a depth cue display of the contents of Z buffer 404. As a result, processor 102 (Figure 1) is free to perform other task on behalf of image processor 110, such as managing a graphical user interface by which the user controls the rescaling of the graphical image, and on behalf of other computer processes executing concurrently with image processor 110. Simultaneously, performance of computer system 100 in rescaling the graphical image is not lessened. Instead, since frame buffer 120 includes video processor 402 (Figure 4) which is a special purpose graphics processor, rescaling the graphical image represented in Z buffer 404 is, in many instances, performed more efficiently by video processor 402 than by a general purpose processor such as processor 102 (Figure 1).

From step 208 (Figure 2), processing transfers through next step 210 and through loop step 204 to repeat steps 206 and 208. Processing according to the loop defined by loop step 204 and next step 210 completes in response to signals so directing as generated by the user, e.g., by selecting a menu option which ceases rescaling the graphical image.

In one embodiment, computer system 100 is the UltraSPARCstation which is available from Sun Microsystems, Inc. of Mountain View, California. Sun, Sun Microsystems, and the Sun Logo are trademarks or registered trademarks of Sun Microsystems, Inc. in the United States and other countries. All SPARC trademarks are used under license and are trademarks of SPARC International, Inc. in the United States and other countries. Products bearing SPARC trademarks are based upon an architecture developed by Sun Microsystems, Inc.

The above description is illustrative only and is not limiting. The present invention is limited only by the claims which follow.

Claims

1. A method for displaying a graphical image, the method comprising:

   storing pixel intensity data in at least one Z coordinate fields in a pixel buffer; and
   initiating a depth cue display in accordance with the Z coordinate fields in the pixel buffer.

2. The method of Claim 1 further comprising:

   specifying a relationship between Z coordinates and display intensities;
   wherein the depth cue display causes display of pixels with selected ones of the display intensities according to the relationship and the respective Z coordinates of each pixel of the pixel buffer.

3. The method of Claim 2 further comprising:

   causing redisplay of the graphical image according to a second relationship between the Z coordinates and the display intensities, which is different from the first-mentioned relationship.

4. The method of Claim 3 wherein the step of causing redisplay comprises:

   specifying the second relationship; and
   initiating a second depth cue display, which is different from the first-mentioned depth cue display, in accordance with the Z coordinate fields in the pixel buffer, wherein the second depth cue display causes display of the pixels of the pixel buffer with selected ones of the display intensities according to the second relationship and the respective Z coordinates of each of the pixels of the pixel buffer.

5. The method of Claim 4 wherein the step of causing redisplay further comprises:

   receiving signals which are generated by a user and which specify the second relationship.

6. The method of Claim 4 further comprising:

   repeating the step of causing redisplay until signals generated by the user indicate that

repeated redisplay is to cease.

7. A computer program product which includes a computer usable medium having computable readable code embodied therein for displaying a graphical image, the computer readable code comprising:

a pixel buffer construction module configured to store pixel intensity data in at least one Z coordinate fields in a pixel buffer; and
a depth cue module operatively coupled to the pixel buffer construction module and configured to initiate a depth cue display in accordance with the Z coordinate fields in the pixel buffer.

8. The computer program product of Claim 7 wherein the computer readable code further comprises:

an intensity mapping module operatively coupled to the depth cue module and configured to specify a relationship between Z coordinates and display intensities;
wherein the depth cue module is further configured to display pixels with selected ones of the display intensities according to the relationship and the respeective Z coordinates of each pixel of the pixel buffer.

9. The computer program product of Claim 8 wherein the computer readable code further comprises:

a redisplay module operatively coupled to the depth cue module and configured to redisplay the graphical image according to a second relationship between the Z coordinates and the display intensities, which is different from the first-mentioned relationship.

10. The computer program product of Claim 9 wherein the redisplay module comprises:

a relationship modification module operatively coupled to the intensity mapping module and configured to cause the intensity mapping module to specify the second relationship; and
a depth cue invocation module operatively coupled to the depth cue module and configured to invoke a second depth cue display by the depth cue module, which is different from the first-mentioned depth cue display, in accordance with the Z coordinate fields in the pixel buffer, wherein the second depth cue display causes display of the pixels of the pixel buffer with selected ones of the display intensities according to the second relationship and the respeective Z coordinates of each of the pixels of the pixel buffer.

11. The computer program product of Claim 10 wherein the redisplay module further comprises:

a user interface module operatively coupled to the relationship modification module and configured to receive signals which are generated by a user and which specify the second relationship.

12. The computer program product of Claim 11 wherein the computer readable code further comprises:

a loop module operatively coupled to the user interface module and configured to repeatedly invoke redisplay of the graphical image by the redisplay module until signals generated by the user indicate that repeated redisplay is to cease.

13. An apparatus for displaying a graphical image, the apparatus comprising:

a pixel buffer construction module configured to store pixel intensity data in at least one Z coordinate fields in a pixel buffer; and
a depth cue module operatively coupled to the pixel buffer construction module and configured to initiate a depth cue display in accordance with the Z coordinate fields in the pixel buffer.

14. The apparatus of Claim 13 further comprising:

an intensity mapping module operatively coupled to the depth cue module and configured to specify a relationship between Z coordinates and display intensities;
wherein the depth cue module is further configured to display pixels with selected ones of the display intensities according to the relationship and the respeective Z coordinates of each pixel of the pixel buffer.

15. The apparatus of Claim 14 further comprising:

a redisplay module operatively coupled to the depth cue module and configured to redisplay the graphical image according to a second relationship between the Z coordinates and the display intensities, which is different from the first-mentioned relationship.

16. The apparatus of Claim 15 wherein the redisplay module comprises:

a relationship modification module operatively coupled to the intensity mapping module and configured to cause the intensity mapping

module to specify the second relationship; and

a depth cue invocation module operatively coupled to the depth cue module and configured to invoke a second depth cue display by the depth cue module, which is different from the first-mentioned depth cue display, in accordance with the Z coordinate fields in the pixel buffer, wherein the second depth cue display causes display of the pixels of the pixel buffer with selected ones of the display intensities according to the second relationship and the respeective Z coordinates of each of the pixels of the pixel buffer

17. The apparatus of Claim 16 wherein the redisplay module further comprises:

a user interface module operatively coupled to the relationship modification module and configured to receive signals which are generated by a user and which specify the second relationship.

18. The apparatus of Claim 17 further comprising:

a loop module operatively coupled to the user interface module and configured to repeatedly invoke redisplay of the graphical image by the redisplay module until signals generated by the user indicate that repeated redisplay is to cease.

19. A computer system comprising:

a memory;
a computer processor operatively coupled to the memory;
a computer display device; and
an image processor stored in the memory and which includes at least one computer instructions which are executed within the computer processor to display a graphical image in the computer display device, the image processor comprising:

a pixel buffer construction module configured to store pixel intensity data in at least one Z coordinate fields in a pixel buffer; and

a depth cue module operatively coupled to the pixel buffer construction module and configured to initiate a depth cue display in accordance with the Z coordinate fields in the pixel buffer.

20. The computer system of Claim 19 wherein the image processor further comprises: an intensity mapping module operatively coupled to the depth cue module and configured to specify a relationship between Z coordinates and display intensities;

wherein the depth cue module is further configured to display pixels in the computer display device with selected ones of the display intensities according to the relationship and the respeective Z coordinates of each pixel of the pixel buffer.

21. The computer system of Claim 20 wherein the image processor further comprises:

a redisplay module operatively coupled to the depth cue module and configured to redisplay the graphical image in the computer display device according to a second relationship between the Z coordinates and the display intensities, which is different from the first-mentioned relationship.

22. The computer system of Claim 21 wherein the redisplay module comprises:

a relationship modification module operatively coupled to the intensity mapping module and configured to cause the intensity mapping module to specify the second relationship; and

a depth cue invocation module operatively coupled to the depth cue module and configured to invoke a second depth cue display by the depth cue module, which is different from the first-mentioned depth cue display, in accordance with the Z coordinate fields in the pixel buffer, wherein the second depth cue display causes display in the computer display device of the pixels of the pixel buffer with selected ones of the display intensities according to the second relationship and the respeective Z coordinates of each of the pixels of the pixel buffer.

23. The computer system of Claim 22 wherein the redisplay module further comprises:

a user interface module operatively coupled to the relationship modification module and configured to receive signals which are generated by a user and which specify the second relationship.

24. The computer system of Claim 23 wherein the image processor further comprises:

a loop module operatively coupled to the user interface module and configured to repeatedly invoke redisplay of the graphical image by the redisplay module until signals generated by the user indicate that repeated redisplay is to cease.

25. A system for distributing code (i) which is stored on a computer-readable medium, (ii) which is executable by a computer, and (iii) which includes at least one module, each of which in turn is configured to carry out at least one function to be executed by the computer, the system comprising:

a pixel buffer construction module configured to store pixel intensity data in at least one Z coordinate fields in a pixel buffer; and
a depth cue module operatively coupled to the pixel buffer construction module and configured to initiate a depth cue display in accordance with the Z coordinate fields in the pixel buffer.

26. The system of Claim 25 further comprising:

an intensity mapping module operatively coupled to the depth cue module and configured to specify a relationship between Z coordinates and display intensities;
wherein the depth cue module is further configured to display pixels with selected ones of the display intensities according to the relationship and the respective Z coordinates of each pixel of the pixel buffer.

27. The system of Claim 26 further comprising:

a redisplay module operatively coupled to the depth cue module and configured to redisplay the graphical image according to a second relationship between the Z coordinates and the display intensities, which is different from the first-mentioned relationship.

28. The system of claim 27 wherein the redisplay module comprises:

a relationship modification module operatively coupled to the intensity mapping module and configured to cause the intensity mapping module to specify the second relationship; and
a depth cue invocation module operatively coupled to the depth cue module and configured to invoke a second depth cue display by the depth cue module, which is different from the first-mentioned depth cue display, in accordance with the Z coordinate fields in the pixel buffer, wherein the second depth cue display causes display of the pixels of the pixel buffer with selected ones of the display intensities according to the second relationship and the respective Z coordinates of each of the pixels of the pixel buffer.

29. The system of Claim 28 wherein the redisplay module further comprises:

a user interface module operatively coupled to the relationship modification module and configured to receive signals which are generated by a user and which specify the second relationship.

30. The system of Claim 29 further comprising:

a loop module operatively coupled to the user interface module and configured to repeatedly invoke redisplay of the graphical image by the redisplay module until signals generated by the user indicate that repeated redisplay is to cease.

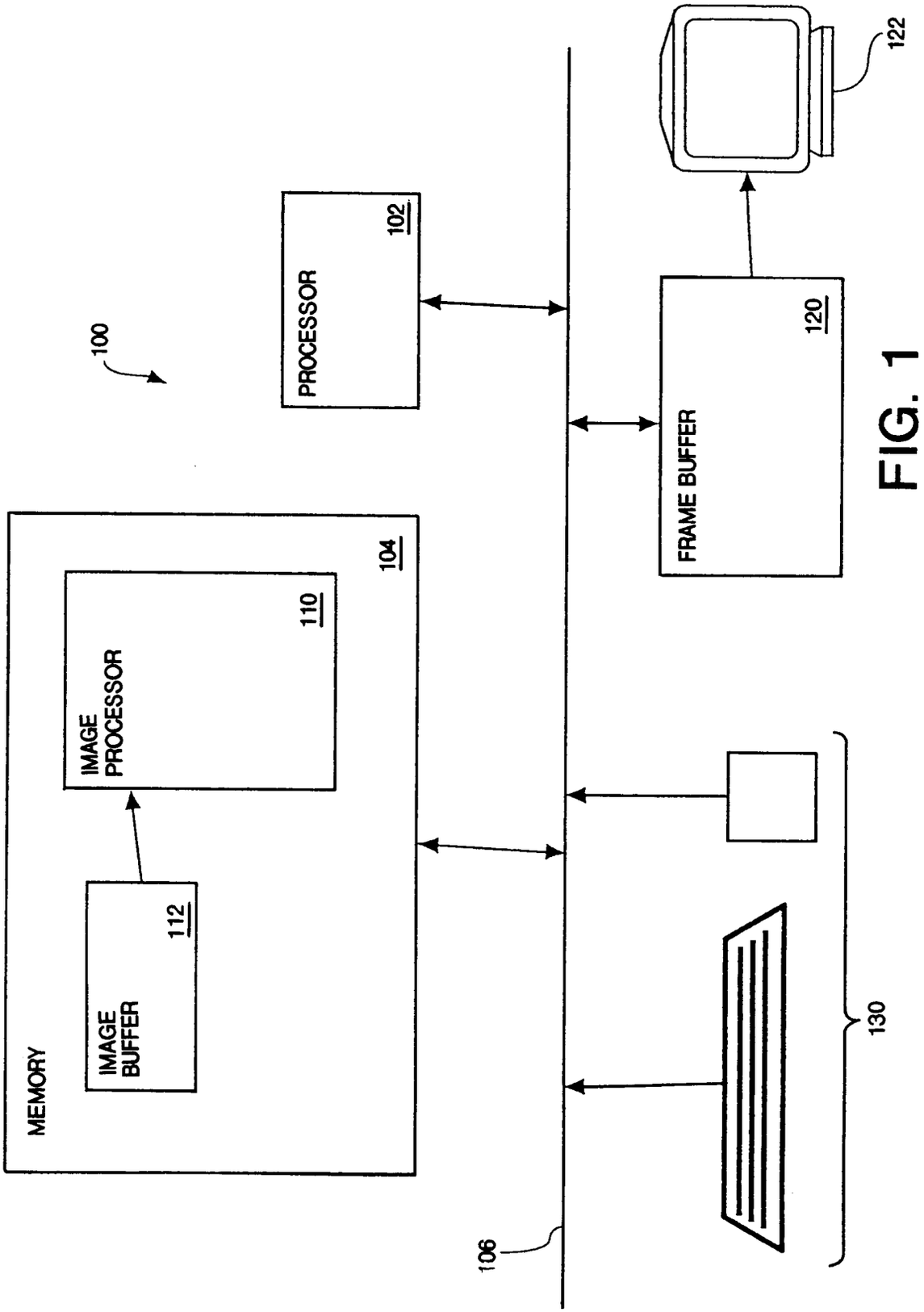

100
PROCESSOR
102
122
FRAME BUFFER
120
MEMORY
104
IMAGE PROCESSOR
110
IMAGE BUFFER
112
130
106

FIG. 1

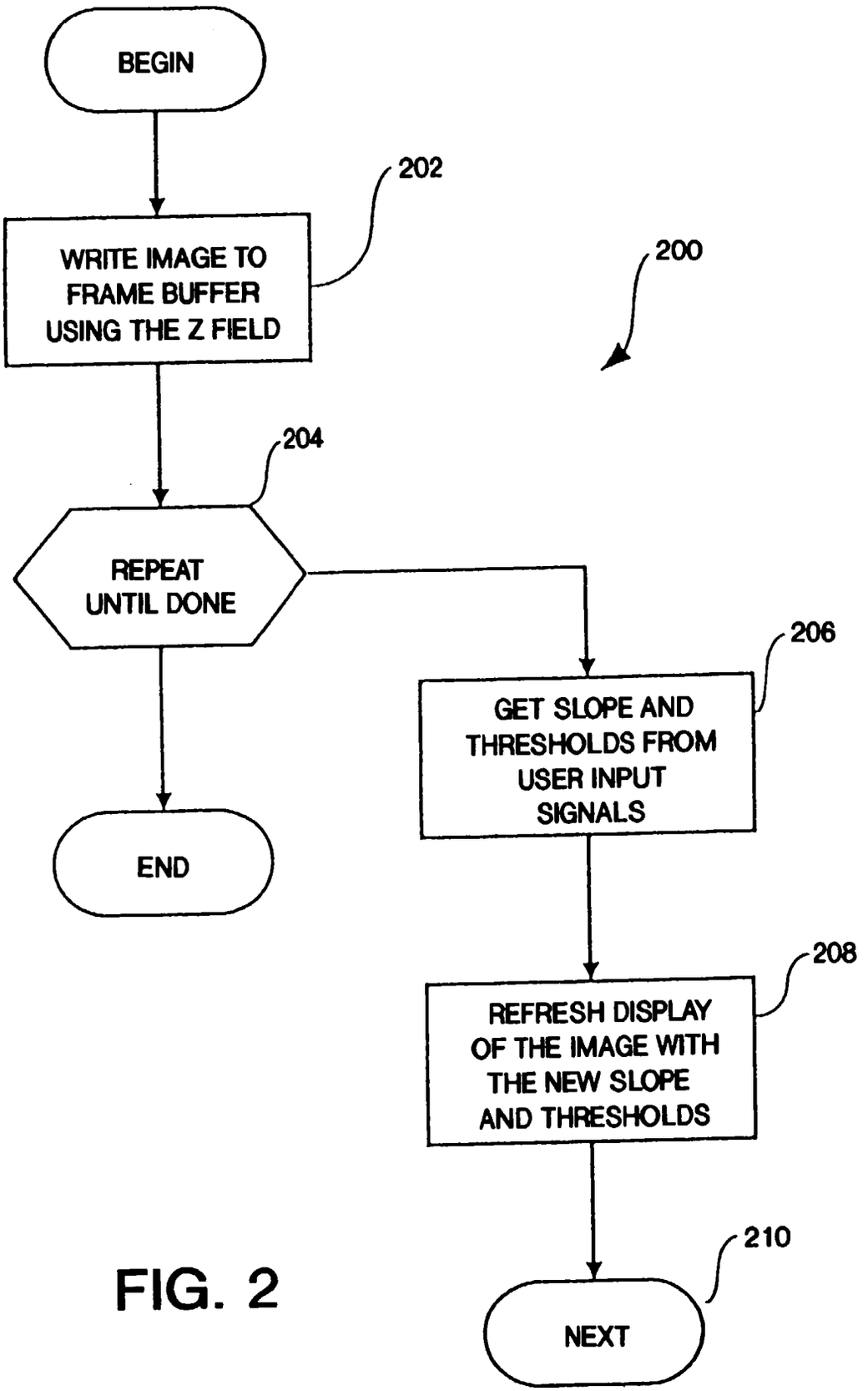

BEGIN
202
WRITE IMAGE TO FRAME BUFFER USING THE Z FIELD
200
204
REPEAT UNTIL DONE
206
GET SLOPE AND THRESHOLDS FROM USER INPUT SIGNALS
END
208
REFRESH DISPLAY OF THE IMAGE WITH THE NEW SLOPE AND THRESHOLDS
210
NEXT

FIG. 2

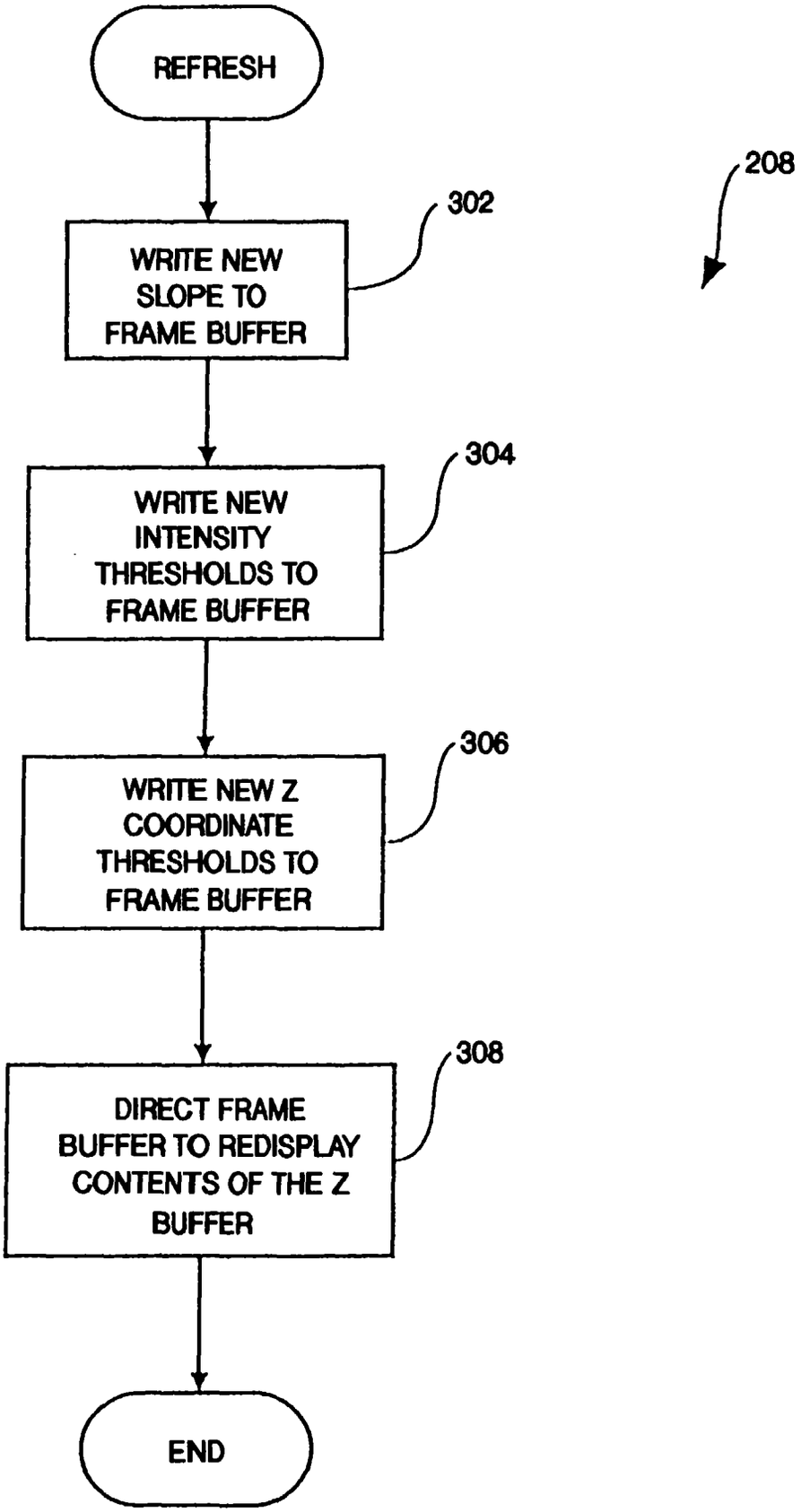

REFRESH
208
302
WRITE NEW SLOPE TO FRAME BUFFER
304
WRITE NEW INTENSITY THRESHOLDS TO FRAME BUFFER
306
WRITE NEW Z COORDINATE THRESHOLDS TO FRAME BUFFER
308
DIRECT FRAME BUFFER TO REDISPLAY CONTENTS OF THE Z BUFFER
END

FIG. 3

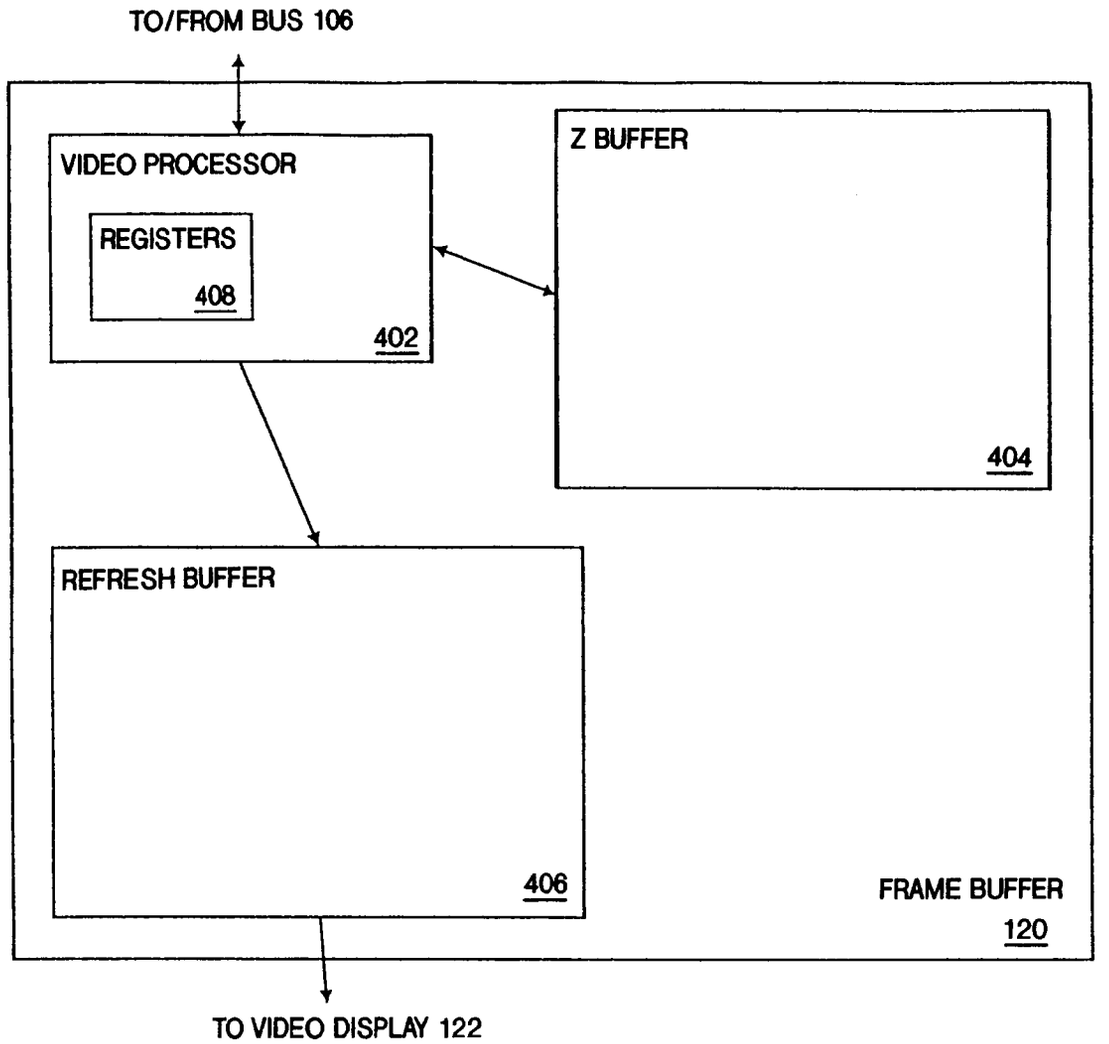

TO/FROM BUS 106
VIDEO PROCESSOR
REGISTERS
408
402
Z BUFFER
404
REFRESH BUFFER
406
FRAME BUFFER
120
TO VIDEO DISPLAY 122

FIG. 4

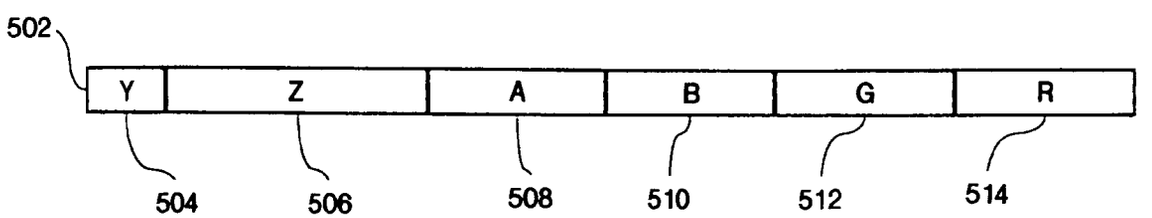

502
Y
Z
A
B
G
R
504
506
508
510
512
514

FIG. 5

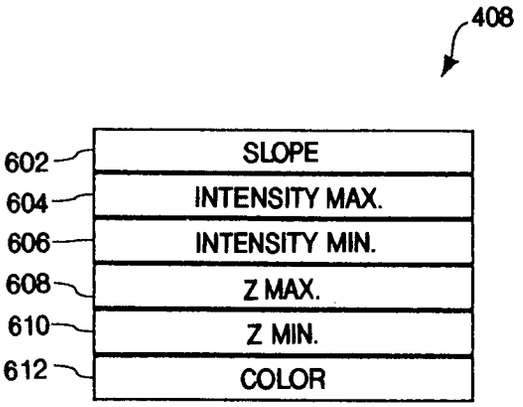

408
602
SLOPE
604
INTENSITY MAX.
606
INTENSITY MIN.
608
Z MAX.
610
Z MIN.
612
COLOR

FIG. 6

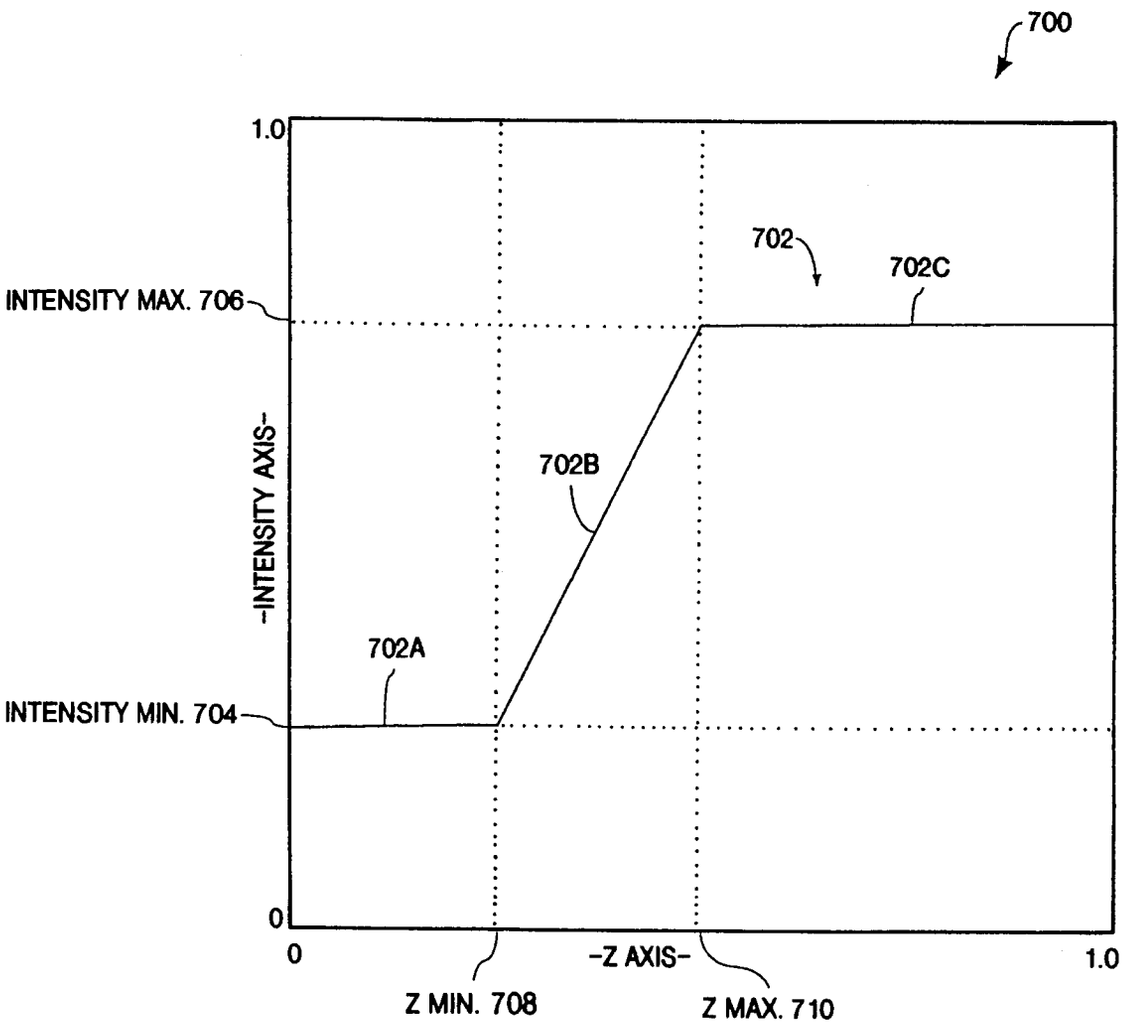

700
1.0
INTENSITY MAX. 706
-INTENSITY AXIS-
INTENSITY MIN. 704
0
0
-Z AXIS-
1.0
Z MIN. 708
Z MAX. 710
702
702C
702B
702A

FIG. 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 11 0793

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 294 482 A (YOKOGAWA MEDICAL SYST) * page 1, paragraph 2 - page 4, line 23 * * page 7, line 2 - line 23; figure 1 * ---		G09G1/16 G09G5/10
A	WO 95 35561 A (HONEYWELL INC) * page 1, line 9 - line 30 * * page 4, line 26 - page 5, line 12 * * page 6, line 2 - page 7, line 3 * ---		
A	EP 0 621 546 A (PHILIPS ELECTRONICS NV) * column 10, line 29 - line 52 * * column 11, line 10 - line 25; figure 6 * ---		
A	EP 0 116 737 A (LEXIDATA CORP) * abstract; figure 2A * -----		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6) G09G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	31 October 1997	Amian, D

CATEGORY OF CITED DOCUMENTS

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