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(54) Title: SCALABLE PIXEL DISTRIBUTION IMAGE CODING SYSTEM FOR COMPRESSION AND DECOMPRESSION OF IMAGES

(57) Abstract

The present invention provides methods and apparatus for representing visual images in compressed digital form. A series of digital images is provided to a random access memory and compressed one frame at a time. The compressor of the present invention divides a frame into a predefined number of blocks. Each block is tested to determine whether the block has a homogeneous color distribution. If the block has a homogeneous color distribution as defined by a selected homogeneity test, each pixel in that block is encoded with a single color value. If the block does not have a homogeneous color distribution, the block is split into two distributions, one distribution with a greater luminance than the average luminance of the first distribution and one distribution with a smaller luminance than the average luminance of the first distribution. These distributions are separately tested for homogeneity and the same process is repeated until the region has been resolved into homogeneous distributions. Distributions are then merged to check whether the merged distribution is homogeneous. After merging, pixels in homogeneous distributions are encoded as a single color.

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SCALABLE PIXEL DISTRIBUTION IMAGE CODING SYSTEM FOR COMPRESSION AND DECOMPRESSION OF IMAGES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The method and apparatus of the present invention relates to the storage, display and playback of digitized visual images, and more particularly, relates to an apparatus and method for compressing and decompressing digitized visual images.

2. Art Background:

Many digital devices, such as computers and video cassette recorders (VCR), are used to store and display visual images, for example, in the form of movies. Digitized visual images require large storage capacities. One frame of a movie requires 153,600 (320 * 240 x 2) bytes if represented in decompressed form for RGB 16 display modes. At 15 frames per second, one second of a movie requires 2,304,000 bytes of storage. Since the amount of storage in digital devices is limited, and since digital devices have limited internal bandwidth, there is a need to represent digitized images in compressed form. The proliferation of digital video in multimedia applications has intensified this need.

One prior art technique to compress digitized monochrome visual images is known as Block Truncation Coding (BTC), first described by Delp and Mitchell. See, E.J. Delp and O.R. Mitchell, "Image Compression Using Block Truncation Coding," IEEE Transactions on Communications, Vol. COM-27, No. 9, pp. 1335-1342, September 1979 (hereinafter the "Delp Method"). This method takes advantage of the human eye's tendency to

perceive the average value of fine detail within a small area when viewing that small area from a distance. If the fine detail is represented with information that preserves the average and standard deviation of the original information, the human eye will not perceive any information loss.

BTC has been extended to color images. The general color BTC method includes the following steps:

1. Decompose the image into non-overlapping n x m blocks.
2. For each block, find the mean luminance value, Y_{avg}, and perform steps 3 to 6.
3. For all pixels in a block whose luminance values are less than or equal to $Y_{avg.}$, find the average color C_{low}.
4. For all pixels in a block whose luminance values are greater than $Y_{avg.}$, find the average color C_{high}.
5. Construct a binary pattern for each block by representing pixels associated with C_{low} as a "0" in the binary pattern, and pixels associated with C_{high} as a 1.
6. Code the block with its two representative color values and the binary pattern, a "0" or a "1" for each pixel.

See, G. Campbell, et al., "Two Bit/Pixel Full Color Encoding," in ACM Computer Graphics, Vol. 20, No. 4, pp. 215-223, Dallas, Aug. 1986). Thus, each pixel within a block is represented as one of two colors. Space is saved because the block is encoded with two colors, four bytes for two RGB 16 colors, to signify the value of the binary pattern plus the 1 bit per pixel in the binary pattern. For example, a block of 4 x 4 pixels is encoded with four bytes to represent the two colors plus 16 bits, one for each

pixel in the block. Thus, the block is encoded with a total of 48 bits or 6 bytes. Without BTC, each pixel is encoded with 16 bits required to represent its RGB 16 color value, a total of 256 bits for a block of 4 x 4 pixels. Thus, BTC results in a compression ratio of 256/48 or 16:3 for a block of 4 x 4 pixels.

The methods that decompose an image into blocks, encode the block as two representative values and encode the pixels in the block as a binary pattern are generally referred to as Binary Pattern Image Coding (BPIC). The block size that can be employed using BPIC depends upon the viewing distance to the display monitor, the pixel resolution and physical dimensions of the display monitor. For instance, see, D. Chen and A.C. Bovik, "Visual Pattern Image Coding," IEEE Transactions on Communications, Vol. COM-38, No. 12, pp. 2136-2146, Dec. 1990. Since neither the color distribution of the images to be compressed nor the extent of information variation with each block are usually known before compression occurs, the block size required to maintain an acceptable level of information is difficult to estimate.

An example of a variation of BPIC encoding is disclosed in United States Patent Application Serial No. 07/965,580 assigned to IBM by Arturo Rodriguez, Mark Pietras and Steven Hancock, filed October, 1992 and titled "HYBRID VIDEO COMPRESSION SYSTEM AND METHOD CAPABLE OF SOFTWARE-ONLY DECOMPRESSION IN SELECTED MULTILMEDIA SYSTEMS." The 07/965,580 application divides an image into regions and examines each region with a homogeneity test. If the region is homogeneous, it is encoded as one color. If the region is not homogeneous, the region is either encoded with BPIC or is divided into quadrants and the

quadrants are encoded as homogeneous regions or with BPIC.

Since the method disclosed in the Serial No. 07/965,580 patent application does not decompose a block beyond quadrants, it suffers from the same limitations as other non-recursive (BPIC) methods. Specifically, since neither the color distribution of the images to be compressed nor the extent of information variation with each block are usually known before compression occurs, the block or quadrant size that is required to maintain an acceptable level of information is difficult to estimate. Ideally, it is desirable to select the block size adaptively according to the information content of the local image region.

Roy and Nasarabadi suggested the use of a method that begins with large blocks, and employs the BTC technique recursively on smaller and smaller blocks by decomposing the block into quadrants, until an appropriate resolution of low information variation is found. See, J.U. Roy and N.M. Nasarabadi," Hierarchical Block Truncation Coding," Optical Engineering, Vol. 30, No. 5, pp. 551-556.

Kamel uses a similar method, using an interval, $[Y_{avg} -t, Y_{avg} +t]$, around the average luminance value of the block to find the best threshold value that minimizes the color mean-square error. See, M. Kamel, C.T. Sun, and L. Guan, "Image Compression By Variable Block Truncation Coding With Optimal Threshold," IEEE Trans. on Signal Processing, Vol. 39, No. 1, pp. 208-212, Jan. 1991.

Recursive block decomposition results in superior compression than non-recursive methods. By adaptively

selecting the minimum number of colors required to represent the block, the image may initially be divided into arbitrarily large regions. Encoding a large homogeneous region as one color results in greater compression than unneccessarily encoding the same large region as a set of smaller regions with the same color since each region must be encoded with that color, which occupies a fixed number of bytes. For example, if a large region is represented as one color, the region is encoded with a two byte color value. If the same region is encoded as 4 regions, each region must be encoded with the two byte color. Thus, in this example, representing the large region as one color saves 6 bytes.

Non-recursive methods such as that described in the Serial No. 07/965,580 application can not encode arbitrarily large regions since, as previously described, the regions into which the image is to be divided must be chosen to be sufficiently small to avoid unacceptable information loss. For an arbitrary image, this choice may not prove optimal since the image may contain single color regions larger than the chosen block size. By dividing these single color regions into smaller regions due to the initial choice of region size, non-recursive methods result in sub-optimal compression.

Although the techniques that recursively divide the image into smaller and smaller blocks result in greater compression than non-recursive methods, the prior art recursive methods have side effects that tend to reduce the quality of the picture. Dividing up the picture into smaller and smaller blocks imposes an artificial block structure on the image and the decompressed image thus tend to appear as if an artificial structure has been imposed upon it.

As will be described, the method and apparatus of the present invention does not impose an artificial structure on an image. The method allows arbitrary shaped objects within a block to retain their original boundaries instead of superimposing the quadrant decomposition structure of the previous suggested approaches. The method of the current invention thus tends to retain high image quality because the appropriate use of a single color is validated.

To validate the appropriateness of encoding a distribution as a single color, the method of the present invention employs a homogeneity test such as that disclosed in the Serial No. 07/965,580 patent application. As previously described, the method disclosed in the Serial No. 07/965,580 patent application divides an image into regions and examines each region with a homogeneity test. If the region is homogeneous, it is encoded as one color. If the region is not homogeneous, the region is either encoded with BPIC or is divided into quadrants and the quadrants are encoded as homogeneous regions or with BPIC.

Unlike the method disclosed in the Serial No. 07/965,580 patent application, the method and apparatus of the present invention recursively employs a homogeneity test to resolve a block into a series of homogeneous distributions. As will be disclosed, the method and apparatus of the present invention decomposes frames by splitting pixel distributions by luminance characteristics, unlike prior art techniques which split images recursively into smaller and smaller blocks. Thus, as previously stated, the method and apparatus of the present invention does not impose an artificial structure on the image to be

compressed, and thus significantly enhances the quality of the image when decompressed.

Apart from BPIC techniques, another suggested compression technique is based on representing groups of pixels by separate luminance and chrominance values for the group. The International Radio Consultative Committee (CCIR) has prescribed a particular coding methodology for this method. Successive two by two pixel regions of a digitized frame are encoded using an individual one byte luminance value for each pixel, and two bytes of representative color difference (chrominance) values for the four pixel region. Thus, instead of representing the four pixels as 12 bytes, 3 bytes per pixel for RGB24 display modes, the four pixels are represented as 6 bytes for a compression ratio of 50%. For an effective system to convert this compressed signal back to original RGB24 display data, see U.S. Patent 5,262,847, issued Nov. 16, 1993 to Arturo Rodriguez et al.

Thus, there is a need for a compression method that achieves high compression ratios while simultaneously reducing the introduction of distortion in the compressed image. As will be described more fully below, the method and apparatus of the present invention will typically result in a much higher compression ratio than the CCIR encoding methodology.

As will be described, the method and apparatus of the present invention retains the benefits of recursive BPIC techniques without imposing an artificial structure on images. Thus, the method and apparatus of the present invention results in a combination of better image quality, better

compression, low complexity, while simultaneously retaining ease of decompression.

SUMMARY OF THE INVENTION

The present invention provides methods and apparatus for representing color or monochrome visual images in compressed digital form. The methods allow rapid decompression while simultaneously retaining higher image quality than traditional BPIC methods. In accordance with the present invention, a visual image or a series of related visual images, such as a sequence of frames in a movie, is stored in digital or analog form and is provided to a compressor of the present invention. A series of digital images is provided to a random access memory (RAM) and compressed by the central processing unit (CPU) of the computer one frame at a time. A decompressor, following the encoding rules of the compressor, decompresses one frame at a time and provides the decompressed frame to the video RAM of a viewing device, such as a cathode ray tube (CRT).

The compressor of the present invention divides a frame into a predefined number of arbitrary sized non-overlapping contiguous regions, which may be simple blocks. Each block is tested to determine whether the block has a homogeneous color distribution. If the block has a homogeneous color distribution as defined by a selected homogeneity test, each pixel in that block is represented as a single color and only one color is needed to encode the block. If the block does not have a homogeneous color distribution, the block is split into two distributions, P(high) and P(low), where P(high) is that part of the first distribution with a greater luminance than the average luminance of the first distribution, Y_{avg}, and P(low) is that part of the first distribution with an equal or smaller luminance than Y_{avg}. P(high) and P(low) are separately tested for

homogeneity and the same process is applied recursively to each until the region has been resolved into homogeneous pixel distributions.

The compressor also ensures that homogeneous distributions that were split during the splitting process are merged. For example, if a distribution is split into distributions P(high) and P(low), these distributions may be further split into distributions P(high, high), P(high, low), P(low, high) and P(low, low). The compressor checks if P(low, high) merged with P(high, low) results in a homogeneous distribution. If so, the merged distribution is encoded as a single color.

Each homogeneous distribution within a block is encoded as a single color and a different binary code representing each color is assigned to each homogeneous distribution. For example, if a block contains two homogenous color distributions, red and black, the color red may be assigned the binary code "0" and the color black the binary code "1".

To increase the compression ratio, the compressor uses frame differencing techniques to take advantage of redundancy between successive frames.

Following the rules of the compressor, a decompressor of the present invention reconstructs the color of each pixel. Continuing with the above example, if the color red is assigned the binary code "0" and the color black the binary code "1", the decompressor substitutes the full color value for red, two bytes for RGB 16 display modes, for each pixel encoded as a "0" and substitutes the color black for each pixel encoded as a "1." The decompressor associates colors with their corresponding patterns by

following the same rules the compressor uses to assign patterns to colors.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is an overview of a system incorporating the teachings of the present inventor for compressing and storing digital images and decompressing and displaying the original images.

FIGURE 2 is a functional block diagram of the compression and decompression system of the present invention.

FIGURE 3 illustrates an exemplary image frame to be compressed.

FIGURE 4 illustrates the division of an exemplary image frame into blocks.

FIGURE 5 illustrates a representative luminance distribution for a homogeneous block.

FIGURE 6 illustrates a representative luminance distribution for a non-homogeneous block.

FIGURES 7a and **7b** illustrate the division of the distribution of **FIGURE 6** into two separate distributions.

FIGURES 8a and **8b** illustrate the division of the distribution of **FIGURE 7a** into two separate distributions.

FIGURES 8c and **8d** illustrate the division of the distribution of **FIGURE 7b** into two separate distributions.

FIGURE 9 illustrates distribution formed by the merger of the distributions of **FIGURES 8b** and **8c**.

FIGURE 10a illustrates another example of a luminance distribution of a non-homogenous block.

FIGURES 10b and **10c** illustrate the division of part of the distribution of **FIGURE 10a** into two distributions.

FIGURE 10d illustrates a distribution formed by the merger of the distributions of part of **FIGURE 10a** and **FIGURE 10b**.

FIGURE 11 illustrates the compression format of a block used by the preferred embodiment of the present invention.

FIGURES 12a through **12h** are a flow chart representing the method of the present invention.

FIGURE 13 is a flow chart representing the method of the present invention used in conjunction with pre-frame differencing.

FIGURE 14 is a flow chart representing the method of the present invention used in conjunction with post-frame differencing.

NOTATION AND NOMENCLATURE

The detailed descriptions which follow are presented largely in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art.

An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. These steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It proves convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms,

numbers, or the like. It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

Further, the manipulations performed are often referred to in terms, such as adding or comparing, which are commonly associated with mental operations performed by a human operator. No such capability of a human operator is necessary, or desirable in most cases, in any of the operations described herein which form part of the present invention; the operations are machine operations. Useful machines for performing the operations of the present invention include general purpose digital computers or other similar digital devices. In all cases there should be borne in mind the distinction between the method operations in operating a computer and the method of computation itself. The present invention relates to method steps for operating a computer in processing electrical or other (e.g. mechanical, chemical) physical signals to generate other desired physical signals.

The present invention also relates to apparatus for performing these operations. This apparatus may be specially constructed for the required purposes or it may comprise a general purpose computer as selectively activated or reconfigured by a computer program stored in the computer. The algorithms presented herein are not inherently related to a particular computer or other apparatus. In particular, various general purpose machines may be used with programs written in accordance with the teachings herein, or it may prove more convenient to construct more specialized apparatus to perform the

required method steps. The required structure for a variety of these machines will appear from the description given below.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, numerous specific details are set forth, such as the system in which compression and decompression is to occur, the division of a visual image into blocks, exemplary shapes of pixel distributions and the encoding of pixel distributions. However, it will be apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well known circuits and structures are not described in detail in order not to obscure the present invention unnecessarily.

Figure 1 illustrates one exemplary system for compressing digital data, storing the compressed data, and regenerating the original data according to the present invention. Shown in **Figure 1** is a central processing unit (CPU) **14**, random access memory (RAM) **16**, a read/write storage device **12**, a read only memory (ROM) **18**, a network interface device **21**, a display buffer **32**, an input/output device **30** and a source of decompressed data, a laser disk **26**, a video cassette recorder (VCR) **28**, or a camera **29**. As shown, these elements communicate with each other over a bus **20**. The decompressed data is provided by the laser disc player **26**, the VCR **28**, the camera **29**, or other device through control commands exercised by the input/output device **30**. The analog signal from the laser disk player **26**, the VCR **28** or the camera **29** is provided to an analog to digital (A/D) converter **22**, which converts the analog image into a digital

representation which is color converted to the desired color format (e.g., RGB 16) by color converter **24**. Alternatively, if a color converter circuit does not exist, the CPU **14** may conduct the color conversion as part of the compression method. The digital image is transmitted one frame at a time to the RAM **16** over the BUS **20**.

The CPU **14** compresses an image frame provided to the RAM **16**. The frame by frame compression of the present invention permits the system to use frame differencing methods at the block level, whereby comparisons are made between consecutive frames, and blocks with data common to consecutive frames are represented with a short codeword indicating commonality that comprises fewer bits than the bit pattern with associated colors normally needed to represent the data. This technique allows good compression in the context of a series of visual images such as a sequence of frames in a movie, since there is potentially identical information between consecutive frames.

In the system illustrated in **Figure 1**, the CPU **14** executes compression software to compress the image frame. The CPU **14** compresses the frame stored in the RAM **16**, and transmits the compressed frame to the read/write storage device **12** and/or to the network interface device for ultimately transmitting the compressed image to a remote destination through a digital network **31**. Subsequent frames are similarly processed until the entire sequence of frames is compressed and stored in the storage device **12** or transmitted over the digital network **31**.

To regenerate the original image, the compressed frames, one at a time, are provided over

the BUS **20** from the storage device **12** into the RAM **16**. In the case of a remote computer, the frames arrive through the digital network **31** to the network interface device **21** and are either transmitted from the network interface device **21** to the storage device **12** or to the RAM **16** or both. The CPU **14** decodes the compressed data and transmits the regenerated image to the display buffer **32**. As illustrated, the display buffer **32** is coupled to a digital to analog (D/A) converter **34**, which in turn is coupled to a display **36**. The CPU **14** is synchronized with the display buffer **32** such that the frames are played back at the proper speed on the display **36** without exceeding the capacity of the display buffer **32**.

Display **36** has a typical display resolution, 640 pixels in the horizontal and 480 pixels in the vertical. Common physical dimensions of display **36** range from 13 to 16 inches in the diagonal. As will be described, the method and apparatus of the present invention will work with displays of any size or resolution.

Turning to the processing performed by CPU **14**, **Figure 2** illustrates a block diagram of the compressor of the present invention. In the diagram of **Figure 1**, the compressor illustrated in **Figure 2** is disposed within the CPU block **14**. A digital signal **42** for a frame stored in the RAM **16** is provided to the color conversion method **40** which converts the digital image **42** into the desired color format in the absence of the color converter circuit **24**. The correct color bit stream **44** is forwarded to a luminance computation method **44**, which computes the luminance values of the pixels in the frame. The luminance distributions of the frame are

analyzed by luminance distribution analyzer **50**, which will be described more fully below, and the results of the analysis are provided to an encoder **54**. The luminance analyzer **50** determines which pixels within a block will be grouped together and represented by the same color. To represent each group in a block with a single color, the encoder **54** processes the original luminance **46** and color **48** signals to determine the values of the colors that will represent each grouping.

As in color BTC encoding, pixels with different colors may be represented as the same color and "compression" results because pixels are encoded with fewer bits than if the encoding had to reflect all possible colors.

Figure 3 illustrates a typical image **62**, comprising one frame out of a continuous sequence, that is to be compressed. The image **62** is defined as an array of pixels **60**, wherein each pixel has a corresponding color, represented in digital form in RAM memory **16**, as previously described. For RGB 16 color format, each pixel may represent one of 65,536 different colors.

Referring now to **Figure 4**, the method of the present invention divides the image **62** into non-overlapping contiguous blocks **64**. In the preferred embodiment, each of the blocks **64** is defined by dimensions greater than would typically be employed in traditional BPIC methods. As previously discussed, dividing an image into larger blocks results in greater compression than if the image is divided into relatively smaller blocks. It will be apparent that a variety of block sizes may be chosen. Further, it will be appreciated that the

image may be divided into geometrical patterns other than squares. However, to maintain ease of decompression, rectangular regions are preferable.

Each of the blocks **64** is tested to determine whether it may be represented by one color. A block will typically have a distribution of colors. If most of these colors are very close to one color, it may be possible to represent the entire block as one color. If the test is properly devised, the loss in information caused by representing pixels with slightly different colors as one color will not be perceived by the human eye. In this Specification, a block that may be represented as one color is referred to as being "homogeneous."

The first step in testing for homogeneity is to generate a luminance distribution of each block **64**. When the block size is large (i.e., 16 pixels x 16 pixels or 32 pixels x 32 pixels) as permitted by this invention, it is preferable to collect the luminance information of the block in a histogram to eliminate scanning the block successively to compute and detect its homogeneous pixel distributions. Since information within a block tends to have little dispersion, by keeping the minimum and maximum values of the luminance range in a block and its histogram, it becomes more computationally efficient to access the information in the histogram than to re-scan the block to successively split non-homogeneous pixel distributions or to merge adjacent homogeneous pixel distributions, steps that will be described below.

Referring now to **Figure 5**, a luminance distribution **74** of a block **64** that is homogeneous under the test of the present method is illustrated.

In the diagram, the horizontal (x) axis **72** represents luminance and the vertical (y) axis **70** represents the number of pixels with a particular luminance value. The luminance of pixels is employed to detect similarities in color since the luminance value of a pixel contains the proper proportion of red, blue and green to facilitate detection of color similarities. Colors that appear more like one another to the human eye have luminance values that are closer together than colors that appear more dissimilar to the human eye.

If a block **64** is comprised of pixels that are all sufficiently close to one color, and thus sufficiently close to one luminance value, the method of the present invention represents the entire block as that one color. The less deviation the curve has around the average luminance, the more accurately the image may be represented as one color.

Whether a curve has a sufficiently small deviation around the average luminance to be represented as one color is determined in the preferred embodiment by the following test, as disclosed in United States Patent Application Serial No. 07/965,580 assigned to IBM by Arturo Rodriguez, Mark Pietras and Steven Hancock, filed October, 1992 and titled "HYBRID VIDEO COMPRESSION SYSTEM AND METHOD CAPABLE OF SOFTWARE-ONLY DECOMPRESSION IN SELECTED MULTILMEDIA SYSTEMS." S is defined as the variance (standard deviation) in luminance of the entire image, and T is defined as the variance in luminance of the pixel distribution being tested for homogeneity. If a pixel distribution is defined as homogeneous if Q percent or more of its pixels

belong to the same class, then it is then said to be homogeneous if it satisfies the expression of $T < S(Q(1-Q))^{1/2}$. Q is chosen to be higher for distributions with relatively few pixels and lower for distributions with relatively many pixels since the tolerance for error increases as the distribution size increases. An examplary choice of Q for a distribution with 16 pixels is 0.93. An examplary choice of Q for a distribution with 1024 pixels is 0.85. The proper choice of Q for a distribution is within the capability of a person of ordinary skill in the art and will not be discussed further.

Since pixel distributions of perceptually homogeneous image regions are asymmetrical, both a left and right standard deviation of the pixel distribution in question are measured and they both must satisfy the test for the distribution to be deemed homogeneous.

An alternative homogeneous test is to employ an edge detection operator (i.e., a 2-D first order differential operator) spatially at each pixel in the block and to compute the magnitude of such operator at each pixel. If the magnitude of the edge detection operator is small (below a threshold) for each pixel in distribution in question, the pixel distribution is deemed homogeneous since there is no significant spatial change.

If the complete pixel distribution of the block satisfies the homogeneity test, it is represented by a single color. The single color of the block is derived by calculating the average color of the pixels in the homogeneous block. How to calculate the average color of a group of pixels is well known

in the art and will not be discussed. The representation of the block as a bit stream will be discussed below.

A block may have a sufficiently broad mix of colors that it may not be represented as one color without an unacceptable loss in the fidelity of the decompressed image. Accordingly, a block with this type of distribution will fail the above homogeneity test. An exemplary distribution **75** of a block that fails the homogeneity test is shown in **Figure 6**.

In accordance with the teachings of the present invention, the distribution **75** that fails the homogeneity test is split into two pixel distributions **80** and **82**, as illustrated in **Figure 7**. The distribution **75** is split in the following fashion: the average luminance of the distribution **75** of **Figure 6** is calculated, and those pixels with a greater luminance than average are placed into a high distribution **82**, as shown in **Figure 7(b)**, while those pixels with an equal or lesser luminance than this average are placed into a low distribution **80**, as shown in **Figure 7(a)**. Thus, the block with the distribution shown in **Figure 6** is split by luminance distribution, rather than by physical area (i.e. division of the block into smaller blocks), as in prior art recursive BPIC techniques.

The two separate distributions **80** and **82** as shown in **Figures 7(a)** and **7(b)** are each tested for homogeneity with the selected homogeneity test. As previously described, in the preferred embodiment, a distribution in question is said to be homogeneous if both left and right luminance standard deviations are smaller than a threshold. The threshold is

preferably a function of the standard deviation of the luminance of the complete image or frame.

If a distribution **80** or **82** as shown in **Figures 7(a)** and **7(b)** fails the selected homogeneity test, it is again split into two distributions as shown in **Figures 8a, 8b, 8c** and **8d** by calculating the average luminance value of the distribution **80** or **82** respectively to separate the distribution **80** or **82** into a distribution having a greater luminance value than the average and a distribution having an equal or lesser luminance value than the average.

Distribution **80** as shown in **Figure 7(a)** is split into distributions **84** and **86**, as shown in **Figures 8a** and **8b** while distribution **82** as shown in **Figure 7(b)** is split into distributions **88** and **90** as shown in **Figures 8c** and **8d**. The homogeneity test is applied to each distribution **84, 86, 88** and **90**. In the preferred embodiment, each time the test is applied, a distribution in question is said to be homogeneous if both left and right luminance standard deviations are smaller than a threshold. The threshold is preferably a function of the standard deviation of the luminance of the complete image or frame.

The steps of testing for homogeneity and splitting non-homogeneous distributions are recursively applied until the block has been divided into a plurality of homogeneous distributions. Instead of assigning a different color to each homogenous distribution, a merging test is performed to merge homogenous distributions that were split by the splitting process but may actually be a homogeneous distribution when merged.

The distributions **86** and **88** as shown in **Figures 8(b)** and **8(c)** are examples of distributions that are homogenous when merged. As previously discussed, distribution **86** was split from distribution **80**, and distribution **88** was split from distribution **82**. The splitting process of the present invention does not separately check for homogeneity in the merged distribution **92** shown in **Figure 9**. The merged distribution **92** is the addition of the distributions **86** and **88**. The distribution **92** is checked for homogeneity.

In most instances, the merging step of the present invention as described with reference to **Figures 8** through **9**, results in greater compression. By merging together different pixel distributions, and assigning a single color to the merged group instead of assigning two different colors to the different groups, one less color has to be represented in the encoding format.

Figure 10(a) also illustrates a distribution **96** where merging will be proper. The distribution **96** is divided into two distributions, one of which is homogeneous and the other of which is not. As shown in **Figure 10(a)**, the lower half **98** of the distribution **96** is homogenous while the upper half **100** of the distribution **96** is not homogenous, and is divided into two distributions, **102** and **104**, as show in **Figures 10b** and **10c**. The lower half **102** of the upper half **100** of distribution **96**, as shown in **Figure 10(b)**, is merged with the original lower half **98** of the distribution **96** of **Figure 10(a)** to form distribution **106** as shown in **Figure 10(d)**. Distribution **106** is tested for homogeneity. Likewise, if the upper part of the first distribution is homogeneous and the lower part of

the first distribution is not, the higher part of the lower distribution is merged with the higher distribution and the merged distribution checked for homogeneity.

The block **64** is split into distributions, the split distributions are checked for homogeneity and then checked for possible merging until the entire block **64** has been resolved into a series of homogeneous distributions. The flow chart of **Figures 12(a) - 12(h)** is one possible implementation of the recursive process of dividing distributions and merging distributions, as illustrated in **Figure 5** through **Figure 10**, until the entire block **64** is processed and encoded.

Turning to the flow chart shown in **Figures 12(a) - 12(h)**, as shown at step **200** of **Figure 12(a)**, a block B_i is retrieved from a frame being compressed. The block B_i is tested for homogeneity at step **202**. If the block is homogeneous, the average color of the pixels in the block is computed as shown in step **206** and the block is encoded at step **208** as will be further described below.

If the block is not homogeneous, step **204** branches to step **210**, which sets a variable next_no_pix_dist equal to one and also sets the first element of the current distribution pointer array P[] to point to all the pixels in block B_i. The process of recursively splitting distributions in half results in a binary tree structure and next_no_pix_dist represents the number of pixel distributions at the next level of the tree after the current level.

If the block B_i is not homogeneous, it is split into two distributions as shown at step **212**, which calls the "pixel distribution splitting procedure" as shown in **Figure 12(b)**. As shown at step **228** of **Figure 12(b)**, the procedure accepts as an input a pixel distribution, which is currently all of the pixels in B_i. At step **230**, the average value of these pixels is computed. At step **232**, the first pixel in the distribution that was split is retrieved and tested to determine whether it is greater than the average luminance, as shown at step **234**. As shown at step **236**, Pixels with lesser or equal luminance than the average are placed in a pixel distribution at the next level of the tree as represented by the array next_P[next_no_pix_dist]. Conversely, as shown at step **242**, pixels with a greater luminance than the average are placed in a pixel distribution at the next level of the tree as represented by the array next_P[next_no_pix_dist + 1]. Thus, the children of the split distribution are ordered by luminance value, from lower luminance to higher luminance, as represented by next_no_pix_dist.

Each pixel in the distribution being split is placed in one of the two distributions as shown in steps **234 - 242** of **Figure 12(b)**. Once the parent distribution has been split, the children are tested for homogeneity as shown in steps **244** and **254**. As shown in steps **246**, **248**, **256** and **260**, homogeneous children are tagged as homogeneous by an array called next_status which is indexed by next_no_pix_dist while non-homogeneous distributions are tagged as non-homogeneous, as shown in steps **250** and **258**. The procedure then exits and control returns to the calling procedure, in this case the

PDIC procedure as shown in **Figure 12(a)** where step **214** is next executed.

Step **214** initializes a variable k to track the current distribution being analyzed. K is initialized to point to the first distribution at the next level. As shown at step **216**, the next_status array is examined to determine if the distribution pointed to by K is homogeneous. If the distribution pointed to is homogeneous, step **216** branches to step **218**, which increments k to point to the next distribution. As shown at step **220**, if k exceeds the number of pixel distributions at the next level, then the method has processed all of the distributions and the "PDIC specification procedure" as shown in **Figure 12(g)** is called.

As shown in **Figure 12(g)**, the PDIC specification procedure encodes each homogeneous distribution with the number of colors represented by the number of homogeneous distributions, which is stored in next_no__pix_dist. As will be described below, step **314** associates colors with n-nary bit patterns to represent those colors. At step **316**, a variable k is set to one and, as shown at steps **318 - 322**, the average color of the final homogeneous distributions is calculated. As shown at steps **324 - 330**, the pixels in the block are encoded with the pattern corresponding to their average color. Step **332** encodes the block as will be described further below and the method exits since it has finished processing the current block.

Returning to step **220** of **Figure 12(a)**, if there are more distributions at the next level, step **220** loops back to step **216** where the next distribution is checked for homogeneity. If the next

distribution is not homogeneous, step **216** branches to step **224**, which switches levels in the tree, as shown in **Figure 12(h)**. A non-homogeneous distribution implies that the tree has a next level which must be analyzed. To analyze the next level of the tree, the arrays that track the current level of the tree must be set equal to the arrays that track the next level of the tree.

As shown in **Figure 12(h)** at step **334**, a variable k is set to one. Variable k is used as an index into the next distribution array, next_P, and the array which tracks homogeneity of the next distributions, next_status. As shown at step **336**, the current level arrays P[] and status[] are set equal to the corresponding next level arrays next_P and next_status for every distribution at the next level. If there are more distributions at the next level, step **340** branches back to step **336**. If there are no more distributions at the next level, the number of pixel distributions at the current level is set equal to the number of pixel distributions at the next level as shown in step **242**. Control is returned to step **226** of **Figure 12(a)**.

All distributions at the new current level must be checked for homogeneity and merging. As described above, a distribution may be merged with a distribution at the same level of the tree or a distribution one level higher in the tree. As shown in **Figures 12(c)-12(f)**, the "next level of tree" procedure performs this function.

Turning to the next level of tree procedure as shown in **Figure 12(c)**, at step **262**, variables k and l that track the children of the split parent are set to 1 and 2 respectively. Thus, k initially

points to the first distribution in the current level and l initially points to the second distribution in the current level. The ordering imposed by steps **236** and **238** of **Figure 12(b)** ensures that distributions are numbered according to luminance, with lower luminance valued distributions indexed with lower numbers than higher luminance valued distributions. As shown at step **264** of **Figure 12(c)**, next_no_pix_dist is incremented by one to track the number of distributions at the next level from the current level. As shown at step **266**, if both the distribution pointed to by k and the distribution immediately to its right (right representing the distributions with relatively higher luminance values) are homogeneous, the homogeneous distributions are propagated down a level in the tree as shown at step **268**. As shown at step **270**, k now will point to the distribution previously pointed to by l and l is incremented to point to the next distribution to the right. If l exceeds the number of pixel distributions, the procedure exits, as shown at step **272**, since all distributions at the current level have been processed. If there are more distributions at the current level, step **272** branches back to step **264**.

Returning to step **266** of **Figure 12(c)**, if one or both of the current pair of distributions being analyzed is not homogeneous, step **266** branches to step **274**, which checks if the distribution pointed to by k is homogeneous and the distribution pointed to by l is not homogeneous. If so, step **274** branches to step **278** on **Figure 12(d)**. The homogeneous distribution P[k] is propagated down the tree as shown in step **278**. At step **280**, the non-homogeneous distribution P[l] is split. The left child of the non-homogeneous distribution P[l] is

checked for homogeneity as shown at step **282** in **Figure 12(d)**. If the left child is homogeneous, it must be merged with P[k] as shown in step **284**. This is analogous to merging P(low) with P(high, low) as shown in **Figures 10(a) - 10(d)**. If the merged distribution is homogeneous, it is propagated down the tree as shown at step **288** and next_no_pix_dist - 1 points to the right child instead of pointing to the left child, which is now merged. If the merged distribution is not homogeneous, then the variable adjustment as shown in step **288** is not performed. Similarly, if the left child was not homogeneous as shown at step **282**, the variable adjustment as shown in step **288** is not performed. After processing the left child for homogeneity and merging, the method passes back to step **270** as shown in **Figure 12(c)** to continue processing towards the higher valued luminance distributions in the tree.

Returning to step **266**, if the current distribution P[k] is non-homogeneous but the distribution to its right P[l] is homogeneous, step **274** branches to step **276** which branches to step **290** as shown in **Figure 12(e)**. The non-homogeneous distribution P[k] is split as shown at step **290** of **Figure 12(e)**. The right child of the non-homogeneous distribution is checked for homogeneity as shown at step **292** of **Figure 12(e)**. If the right child is homogeneous, it is merged with P[l], as shown at step **294**. This is analogous to merging P(high) with P(low, high) as described above. If the merged distribution is homogeneous, it is simply propagated down the tree at the location of the right child, next_no_pix_dist, as shown at steps **296** and **298**. Conversely, if either the merged distribution was not homogeneous or the right child was not homogeneous, P[l] is propagated down the tree as a homogeneous distribution, as shown at step

300. Control passes back to step 270 of Figure 12(c), where processing is continued towards the higher valued luminance distributions in the tree.

Returning to step 266 of Figure 12(c), the final possibility is that neither the current distribution P[k] nor its neighbor to the right P[l] is homogeneous. In this case, step 266 branches to 274 which branches to 276 which branches to step 302 of Figure 12(f). As shown at steps 302 and 304 of Figure 12(f), both the current distribution P[k] and its neighbor to the right P[l] are split. The right child of the lower distribution P[k] and the left child of the higher distribution P[l] must be checked for homogeneity as shown at step 306. If both are homogeneous, they are merged and the merger checked for homogeneity as shown at steps 308 and 310. This is analogous to merging P(low, high) with P(high, low) as illustrated in Figures 6-8. If the merged distribution is homogeneous, the pointer to the right child of the lower distribution P[k] is adjusted to point to the merged distribution and the pointer to the left child of the higher distribution P[l] is adjusted to point to the right child of the higher distribution P[l] so that three distributions, the left child of the low distribution P[k], the merged distribution and the right child of the high distribution P[l], are propagated down the tree. This adjustment is performed at step 312. If either the right child of the lower distribution P[k] or the left child of the higher distribution P[l] are not homogeneous, or the merger is not homogeneous, four distributions, the right and left children of both the low and high distributions P[k] and P[l] are propagated down the tree. Once again, control passes to step 270 of

Figure 12(c) and processing continues toward the right of the tree.

As previously described, the entire current level is checked for homogeneity and merging as performed by the next level of tree procedure as shown in **Figures 12(c)-12(f)**. Once the level as been processed, it must be checked to determine if a new level of the tree must be added. As previously described, checking for a new level is performed by steps **214-220** of **Figure 12(a)**. Once a level contains only homogeneous distributions, the step **220** branches to step **314** as shown in **Figure 12(g)** and the block is subsequently encoded. Thus, the flow chart as shown in **Figures 12(a)-(b)** illustrates a method for recursively resolving a block into homogeneous distributions while merging distributions when appropriate.

In addition to the decomposition of the block **64** into a series of homogeneous distributions, frame differencing techniques are employed to provide for optimal compression of the block **64**. Frame-differencing methods for software-only video codecs exploit redundancy between frames without searching for potential motion displacement.

Frame-differencing by comparison methods are disclosed in a patent application entitled "Hybrid Video Compression Method Amenable to Software-only Decompression in Low-end Multimedia Systems," Serial No. 07/965,580, filed Oct. 1992. The inventors of this patent are Arturo A. Rodriguez, et al. The method and apparatus of the present invention provides an improvement to the method described in the Serial No. 07/965,580 patent application.

In the method and apparatus of the present invention, frame-differencing is performed between successive blocks on a block to block basis. Pre-frame differencing on a block to block basis is performed by considering pixels at the corresponding spatial locations within the blocks or by considering the similarities between local image properties measured within the corresponding blocks. Alternatively, frames can be first compressed with the pixel distribution image coding (PDIC) method of the present invention and post-frame-differencing may then performed by considering the similarities between the data representation produced by the PDIC compression method in each pair of spatially corresponding blocks in every two consecutive frames.

The similarity test performed by the encoder is typically the absolute value of the difference between the luminance value of the spatially corresponding pixels in the blocks of the current frame, F_i, and the previous regenerated frame D_{i-1}. If the absolute difference is less than a specified threshold, the pixel is then deemed to not have changed from the previous reconstructed frame.

Local and global rules are used to allow a degree of lossiness when comparing spatially corresponding blocks. The local rules govern the maximum absolute difference between pixel values in the block that can be tolerated as a function of the values of the two pixels. The global rules monitor the overall accumulated difference that can be tolerated in the set of pixels. Alternatively, the global rule may be enhanced to reduce visible tiling artifacts by enforcing that all pixels along the block boundary satisfy the local rule.

Figure 13 is a flow chart of the video compression method of the current invention using pre-frame differencing. In pre-frame differencing, pixels at corresponding spatial locations within corresponding blocks are compared for similarities. Alternatively, pre-frame differencing may be implemented by considering the similarities between local image properties measured within corresponding blocks. As shown at steps **350-352**, a frame F_i is retrieved and decomposed into non-overlapping blocks. The first block is retrieved at step **354** and pre-frame differencing is performed at step **356**. As shown at step **358** in **Figure 13**, a block is compared with an encoded block in the previous frame corresponding to the block in the current frame. If the block in the current frame did not change, the block is encoded to indicate that it did not change from the corresponding block in the previous frame as shown at step **364** of **Figure 13**. If the block in the current frame did change, however, the PDIC method of the current invention is applied to decompose the block into homogeneous distributions and the distributions are encoded, as shown at blocks **360** and **362**. Steps **366** and **368** ensure that the entire frame is processed.

Figure 14 is a flow chart of the video compression method of the current invention using post-frame differencing. As shown at steps **370** and **372** of **Figure 14**, a frame F_i is retrieved and decomposed into blocks. The PDIC procedure is performed on the first block in the frame as shown at steps **374** and **376**. The PDIC processed block is then compared with the corresponding block in the previous frame as shown at step **380** of **Figure 14**. If the block did not change, it is encoded to indicate that it did not change from the

corresponding block in the previous frame as shown at step **384** of **Figure 14**. If the block did change, however, it is encoded as a series of homogeneous distributions as generated by the PDIC method of the present invention, as shown at step **382**. Steps **386** and **388** ensure that all the blocks in the frame are processed.

Whether pre frame differencing or post frame differencing is used, if a block has changed from a corresponding block in the previous frame, the block is resolved into a series of homogeneous distributions and then encoded. **Figure 11** shows how the block is encoded. A fixed number of bits, color distribution field **110**, fixes the maximum number of colors. For example, 3 bits in this field indicates a maximum of 8 colors. Color distribution field **110** contains the number of homogenous distributions in a block, after the final merging step is performed, up to the maximum permissible value. The next field, color field **112**, contains the colors of the different distributions.

If a block is encoded as one color, the color field **112** contains the color representing the block. The individual pixels of the block are not encoded since each pixel is represented by one color. As discussed below, when the decompressor receives a value of 1 in the color distribution field **110**, the decompressor inserts the color in color field **112** into each pixel in the block of the reconstructed image.

When a block contains two or more colors, individual pixels of the block are encoded in pixel field **114** with a bit pattern that corresponds to the colors represented in the color field **112**. Pixels

that are represented by the first color are coded with a bit pattern corresponding to the value "0". Pixels that are represented by the second color are coded with a bit pattern corresponding to the value "1".

If there are only two colors in the block, the bit pattern following the specification of the colors is a binary pattern to associate the two colors with each pixel in the block. If there are 3 or 4 colors in the block, because there or four homogeneous distributions ere found in the block, then the pattern will consist of 2 bit entries for each pixel in the block to associate the pixels with their corresponding colors. Generalizing, if there are n+1 homogeneous pixel distributions in a block, then pixels with a color C_x, $0 \leq x \leq N$, are encoded as the number x in each entry of the pattern in $\log_2 (n+1)$ bits.

An alternative coding scheme may provide greater compression. If three colors exist in the block and a large proportion of pixels have the color 0, the following pattern may be used:

Color 0 pixels = 0
Color 1 pixels = 10
Color 2 pixels = 11.

The most prevalent color may be chosen as color 0 to maximize compression.

This type of coding may be employed for any number of colors in a block. In one embodiment of the present invention, the compressor computes the number of pixels with the various colors and chooses the coding scheme that results in greater compression. This step comes at the cost of reducing the compression speed, since the apparatus

performing the PDIC method must make these additional calculations.

As previously described, to take advantage of the redundancy in visual images, difference encoding may be employed in conjunction with the PDIC method of the present invention. In the encoding step, a predetermined code may indicate that the pixel color has not changed from its previous value. For example, for a block with three colors, C_0 may be encoded as 00, C_1 as 01, C_2 as 10 and those pixels that have not changed value from the previous frame encoded as 11. As shown in **Figure 11**, one bit **116** may be dedicated for the entire block to indicate that the entire block has not changed from the previous block. It will be appreciated that other prior art data compression techniques may be applied to the bit stream that represents the compressed block. After each pixel in the block has been encoded, the compressor repeats the process on the next block of the frame, until the last block of the frame has been compressed. The compressed frame is stored and the next frame brought into the RAM **16**, as shown in **Figure 1**.

The decompressor is essentially the inverse of the compressor. The decompressor is programmed to parse off a fixed number of bits, color distribution field **110** as shown in **Figure 11**, that represent the number of colors in the block. The decompressor assigns the colors C_0 through C_n with the same bit patterns as the compressor. Thus, if the compressor assigned pixels that are color C_0 the bit pattern 0, the pixels with the bit pattern 0 are substituted with the value of C_0, which is a full color value, 16 bits for RGB 16 display modes. For example, suppose C_0 is the color white with a bit pattern of 0000.

Pixels with the bit pattern 0 are substituted with the bit pattern 0000.

The color distribution field **110** allows the compressor to parse off the correct number of colors, C_0 through C_n, and also to parse off the correct number of bits per pixel, generally, calculated as $\log_2 (n + 1)$ bits.

The decompressed bit stream may then be viewed on the display **36**, as illustrated in **Figure 1**.

SUMMARY

The present invention as described provides methods and apparatus for storing a series of visual images in compressed form. While the present invention has been described with reference to the various figures, it will be appreciated that the figures are for illustration only, and do not limit the spirit and scope of the invention. For example, although the figures have, by necessity, used example distributions of visual frames, an infinite number of distribution shapes are possible. The method and apparatus of the present invention will operate with any such distribution. Further, it will be appreciated that there are many different encoding possibilities for encoding the homogeneous distributions and that the screen may split into a variety of geometric patterns other than blocks. Instead of using luminance to separate the distributions, chrominance or other values that are functions of color may be used. The method of the present invention may process analog images and be implemented by an analog computing device.

Claims.

1. A method for converting an image frame into an encoded data stream, including the steps of:

storing said image frame in a memory;

associating a group of pixels with a region of said image frame;

generating a first color distribution of said group of pixels associated with said region;

testing said first color distribution to determine whether said group of pixels associated with said region has a homogeneous color distribution;

if said group of pixels associated with said region does not have a homogeneous color distribution, dividing said first color distribution into two or more second color distributions;

testing at least one of said second color distributions to determine whether a group of pixels associated with said tested second color distribution has a homogeneous color distribution;

encoding a group of pixels associated with a homogeneous color distribution.

2. The method of claim 1 wherein said first color distribution comprises a luminance distribution of said group of pixels associated with said region.

3. The method of claim 1, wherein said group of pixels associated with said region has a homogeneous color distribution, further including the step of associating said region with a region color and encoding said group of pixels associated with said region as said region color.

4. The method of claim 3, wherein at least one of said groups of pixels associated with said tested

second color distributions does not have a homogeneous color distribution, further including the steps of:

dividing a tested second color distribution associated with a group of pixels that does not have a homogeneous color distribution into two or more third color distributions;

testing at least one of said third color distributions to determine whether a group of pixels associated with said tested third color distribution has a homogeneous color distribution;

if said group of pixels associated with said tested third color distribution has a homogeneous color distribution, associating said tested third color distribution with a third distribution color and encoding said group of pixels associated with said tested third color distribution as said third distribution color.

5. The method of claim **4** wherein each of said second color distributions is tested to determine whether a group of pixels associated with said tested second color distributions is homogeneous.

6. The method of claim **5** further including the steps of:

testing each of said third color distributions to determine whether a group of pixels associated with said tested third color distributions is homogeneous;

if at least one of said groups of pixels associated with said tested third color distributions does not have a homogeneous color distribution, then dividing each of said tested third color distributions into two or more fourth color distributions;

testing each said fourth color distribution to determine whether a group of pixels associated with said tested fourth color distribution has a homogeneous color distribution;

if at least one of said groups of pixels associated with said tested fourth color distributions does not have a homogeneous color distribution, recursively dividing said tested fourth color distributions and testing each resulting color distribution until each tested final color distribution is associated with a group of pixels that has a homogeneous color distribution;

associating each final color distribution with a final distribution color and encoding a group of pixels associated with said final color distribution as one color.

7. The method of claim 3 wherein said step of dividing said first color distribution includes the steps of:

calculating an average luminance of said first color distribution;

associating a group of pixels that have a greater luminance than said average luminance with a high second color distribution; associating a group of pixels that have a smaller luminance than said average luminance with a low second color distribution.

8. The method of claim 3, wherein at least one of said groups of pixels associated with said tested second color distributions does not have a homogeneous color distribution, further including the steps of:

dividing a tested second color distribution associated with a group of pixels that does not have a homogeneous distribution into two or more third

color distributions; testing at least one of said third color distributions to determine whether a group of pixels associated with said tested third color distribution has a homogeneous color distribution;

if at least one of said groups of pixels associated with said tested third color distributions has a homogeneous color distribution, then if at least one of said groups of pixels associated with said tested second color distributions has a homogeneous color distribution, then merging said tested third color distribution associated with a group of pixels with a homogeneous color distribution with said tested second color distribution to form a first merged color distribution;

testing said first merged color distribution to determine whether a group of pixels associated with said first merged color distribution has a homogeneous color distribution;

if said group of pixels associated with said first merged color distribution has a homogeneous color distribution, associating said first merged color distribution with a first merged color distribution color and encoding a group of pixels associated with said first merged color distribution as said first merged distribution color;

if none of said groups of pixels associated with said tested second color distributions has a homogeneous color distribution, then testing a different third color distribution to determine whether a group of pixels associated with said tested different third color distribution has a homogeneous color distribution;

if a group of pixels associated with said

different third color distribution has a homogeneous color distribution, then merging said tested third color distribution with said tested different third color distribution to form a second merged color distribution;

testing said second merged color distribution to determine whether a group of pixels associated with said second merged color distribution has a homogeneous color distribution;

if said group of pixels associated with said second merged color distribution has a homogeneous color distribution, associating said second merged color distribution with a second merged distribution color and encoding said group of pixels associated with said second merged color distribution as said second merged distribution color.

9. The method of claims **1** or **3** wherein said step of testing a color distribution for homogeneity includes the steps of:

determining a standard deviation, T, of said color distribution to be tested;

determining a standard deviation, S, of a color distribution from which said tested color distribution to be tested was derived; and

defining Q as a percentage such that said color distribution to be tested is said to be homogeneous if $T < S\ (Q(1-Q))^{1/2}$.

10. The method of claim **3** wherein said step of associating said first color distribution with a first distribution color includes the steps of generating an average color of said first color distributions and associating said average color with said first color distribution.

11. The method of claim 1 wherein said step of encoding said group of pixels associated with said region includes the steps of:

assigning a number field to indicate that said group of pixels associated with said region has a homogeneous color distribution;

assigning a color field to represent said region color.

12. The method of claim 3 wherein said step of encoding said group of pixels associated with said second color distribution includes the steps of:

assigning a number field to indicate the number of distribution colors to be encoded;

assigning a color field to represent a distribution color to be encoded and associating a bit pattern with said distribution color to be encoded;

encoding a pixel in said region with one of said bit patterns associated with a distribution color such that said pixel associated with a color distribution is encoded with a bit pattern corresponding to the color associated with said color distribution associated with said pixel.

13. The method of claims 1 or 3 wherein said regions comprise squares.

14. The method of claims 11 or 12 further including the step of decoding said encoded data stream, said step including the steps of:

examining said number field;

if said number field indicates a homogeneous region, substituting each pixel in said homogeneous region with a bit pattern in said color field;

if said number field does not indicate a homogeneous region, associating each color in said color field with a bit pattern;

parsing said encoded pixels into separate portions;

substituting for each said separate portion a color associated with said portion.

15. An apparatus for converting an image frame into an encoded data stream, including:

storing means for storing said image frame in a memory;

first associating means for associating a group of pixels with a region of said image frame;

first generating means for generating a first color distribution of said group of pixels associated with said region;

first testing means for testing said first color distribution to determine whether said group of pixels associated with said region has a homogeneous color distribution;

first dividing means for dividing said first color distribution into two or more second color distributions, said first dividing means operative when said group of pixels associated with said region does not have a homogeneous color distribution;

first testing means for testing at least one of said second color distributions to determine whether a group of pixels associated with said tested second color distribution has a homogeneous color distribution;

encoding means for encoding a group of pixels associated with a homogeneous color distribution.

16. The apparatus of claim 15 wherein said first color distribution includes a luminance distribution of said group of pixels associated with said region.

17. The apparatus of claim 15 further including first distribution associating means for associating said region with a region color and second encoding means for encoding said group of pixels associated with said region as said region color, said first distribution associating means and said second encoding means operative when said group of pixels associated with said region has a homogeneous color distribution.

18. The apparatus of claim 15 further including second associating means for associating said second color distribution with a second distribution color.

19. The apparatus of claim 17 wherein said dividing means further includes:

calculating means for calculating an average luminance for a color distribution to be divided;

third associating means for associating a group of pixels that have a greater luminance than said average luminance with a high second color distribution;

fourth associating means for associating a group of pixels that have a smaller luminance than said average luminance with a low second color distribution.

20. The apparatus of claim 17 further including merging means for merging homogeneous distributions.

21. The apparatus of claim 15 or 17 wherein said first and second testing means further include:

first determining means for determining a standard deviation, T, of a color distribution to be tested;

second determining means for determining a standard deviation, S, of a color distribution from which said tested color distribution to be tested was derived; and

defining means for defining Q as a percentage such that said color distribution is said to be homogeneous if $T < S\ (Q(1-Q))^{1/2}$.

22. The apparatus of claim **17** wherein said second associating means further includes average color generating means for generating an average color of a color distribution.

23. The apparatus of claim **17** wherein said second encoding means further includes:

first assigning means for assigning a number field to represent a number of homogeneous color distributions within said region;

second assigning means for assigning a color field to represent a final color or a plurality of final colors to be encoded.

24. The apparatus of claim **22** wherein second encoding means further includes:

bit pattern associating means for associating each of said plurality of final colors with a bit pattern;

pixel encoding means for encoding a pixel in said region with one of said bit patterns associated with a color such that said pixel associated with a color distribution is encoded with a bit pattern corresponding to the color associated with said color distribution associated with said pixel.

25. The apparatus of claim 17 wherein said regions comprise squares.

26. The apparatus of claim 23 further including a decompressor, said decompressor including:

examining means for examining said number field;

substituting means for substituting each pixel in said homogeneous region with a bit pattern in said color field.

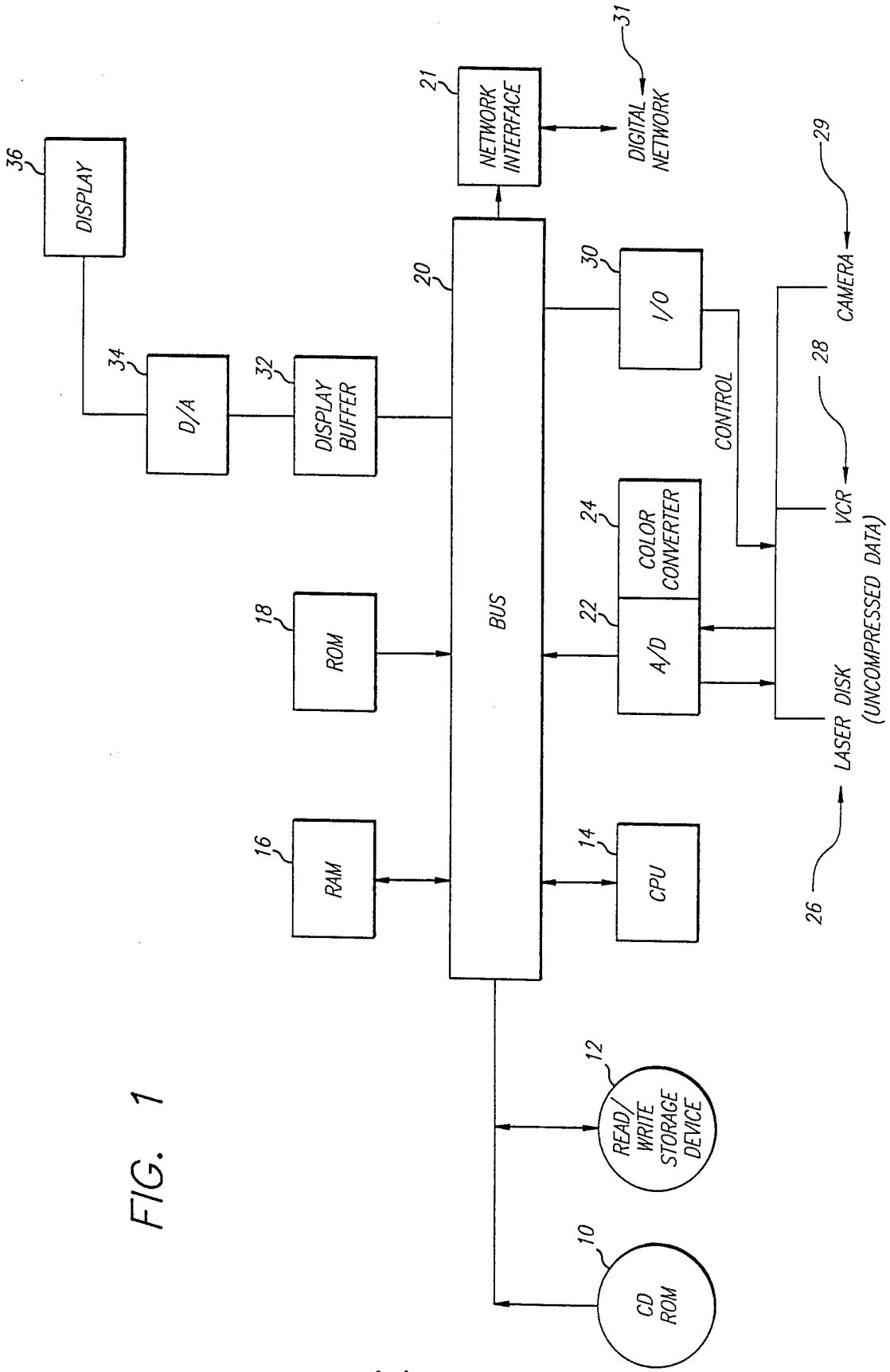


FIG. 1

SUBSTITUTE SHEET (RULE 26)

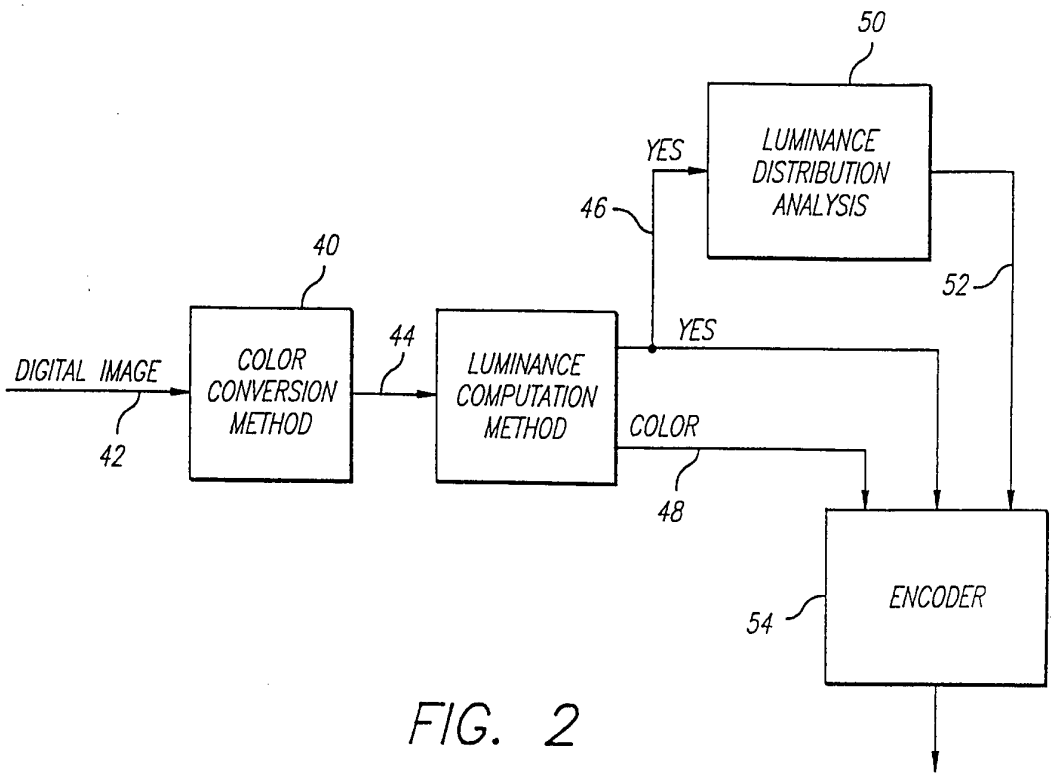

50
LUMINANCE DISTRIBUTION ANALYSIS
YES
46
52
40
DIGITAL IMAGE
42
COLOR CONVERSION METHOD
44
LUMINANCE COMPUTATION METHOD
YES
COLOR
48
54
ENCODER

FIG. 2

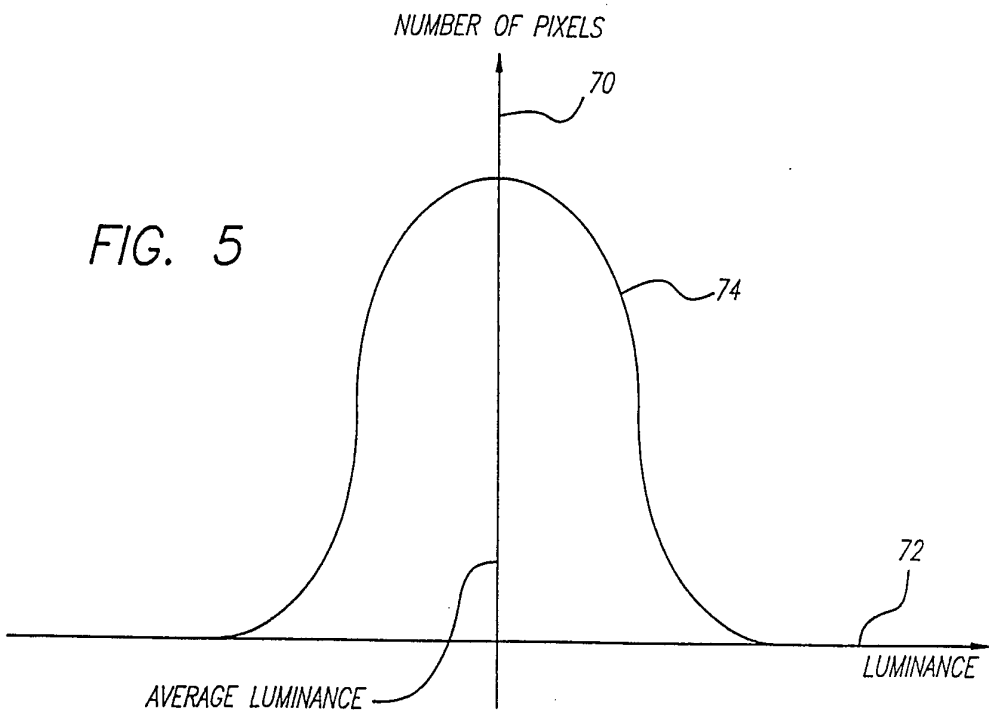

NUMBER OF PIXELS
70
74
72
AVERAGE LUMINANCE
LUMINANCE

FIG. 5

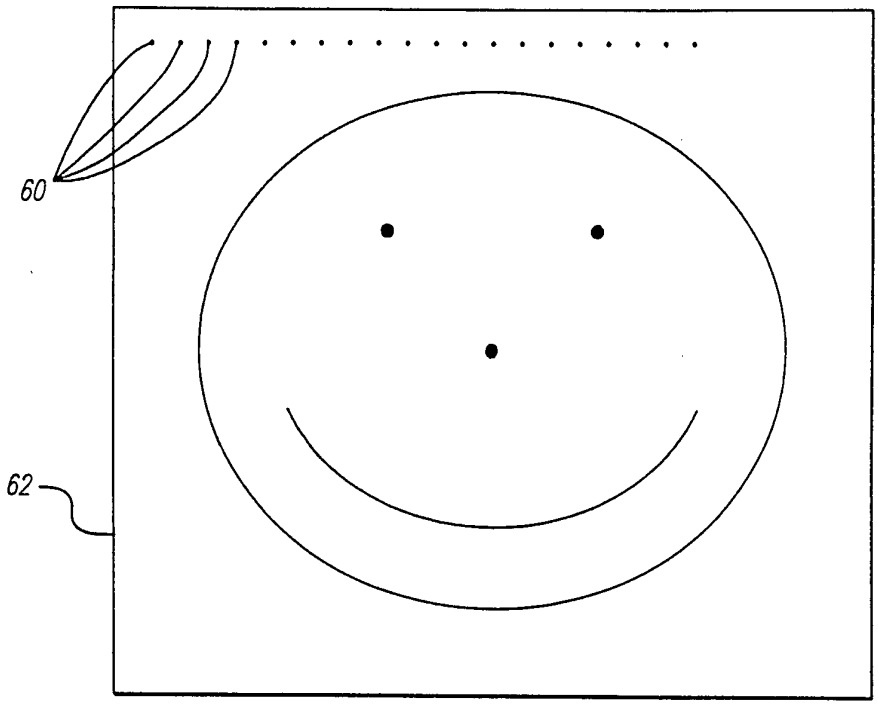


FIG. 3

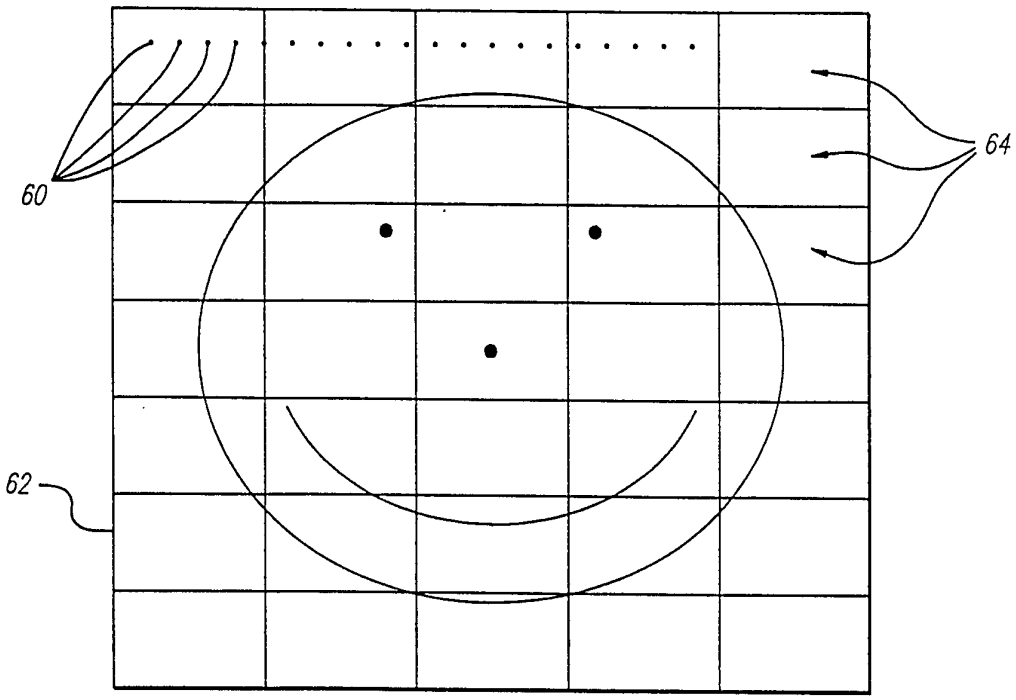
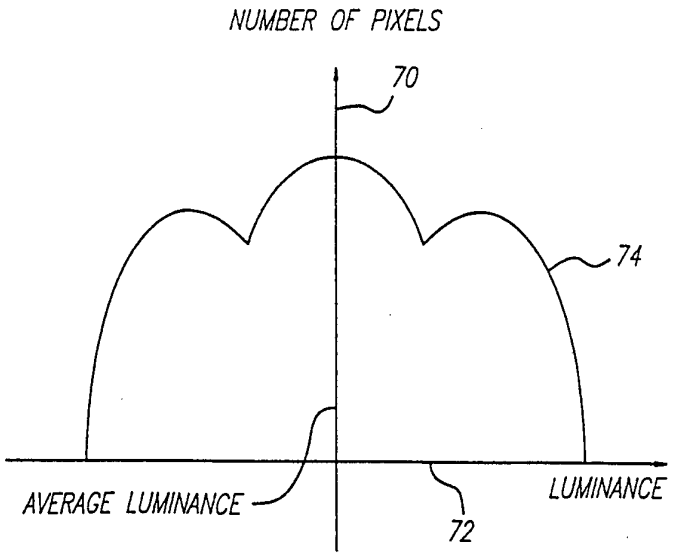


FIG. 4

FIG. 6



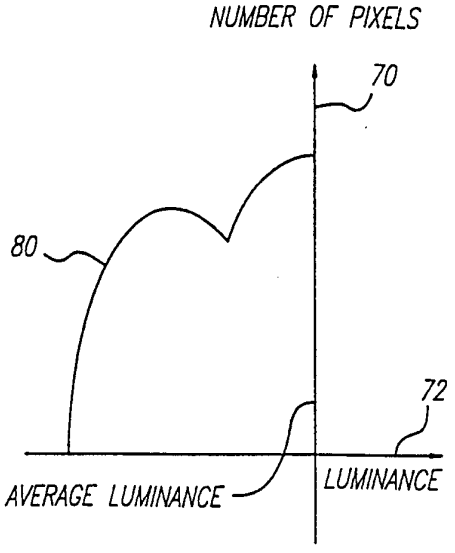


FIG. 7a

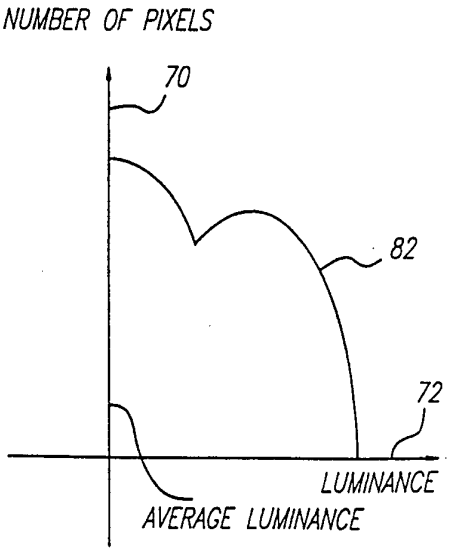


FIG. 7b

RECTIFIED SHEET (RULE 91)
ISA/EP

FIG. 8a

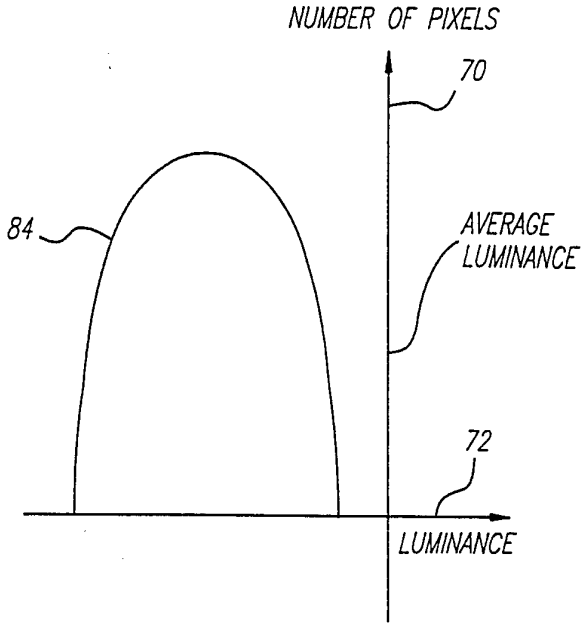
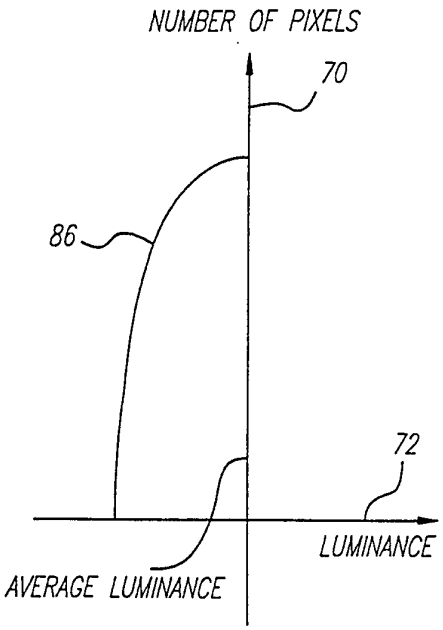


FIG. 8b



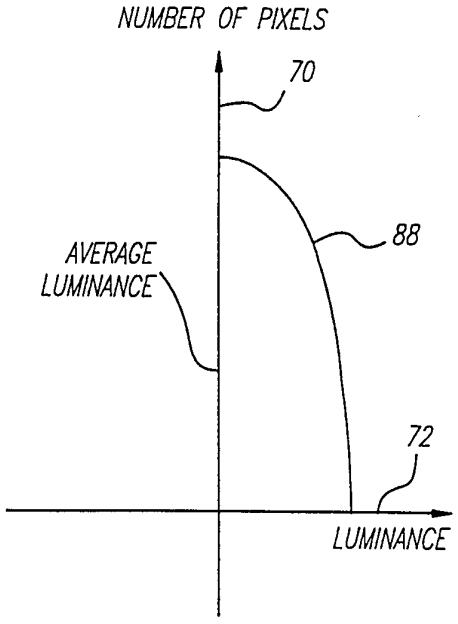


FIG. 8c

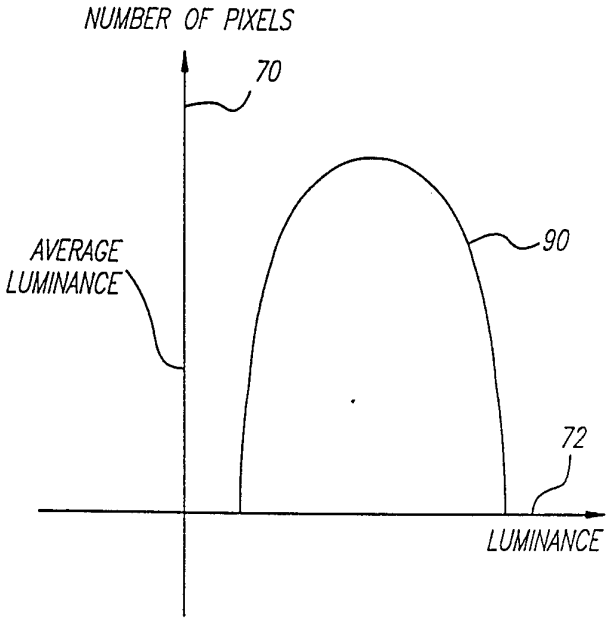


FIG. 8d

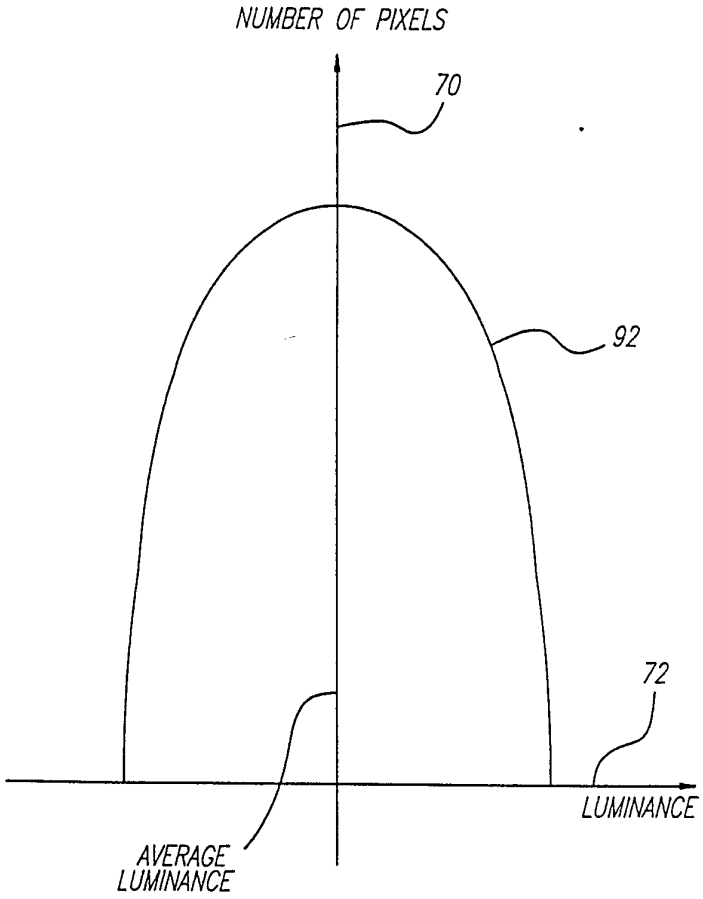

NUMBER OF PIXELS
70
92
72
LUMINANCE
AVERAGE LUMINANCE

FIG. 9

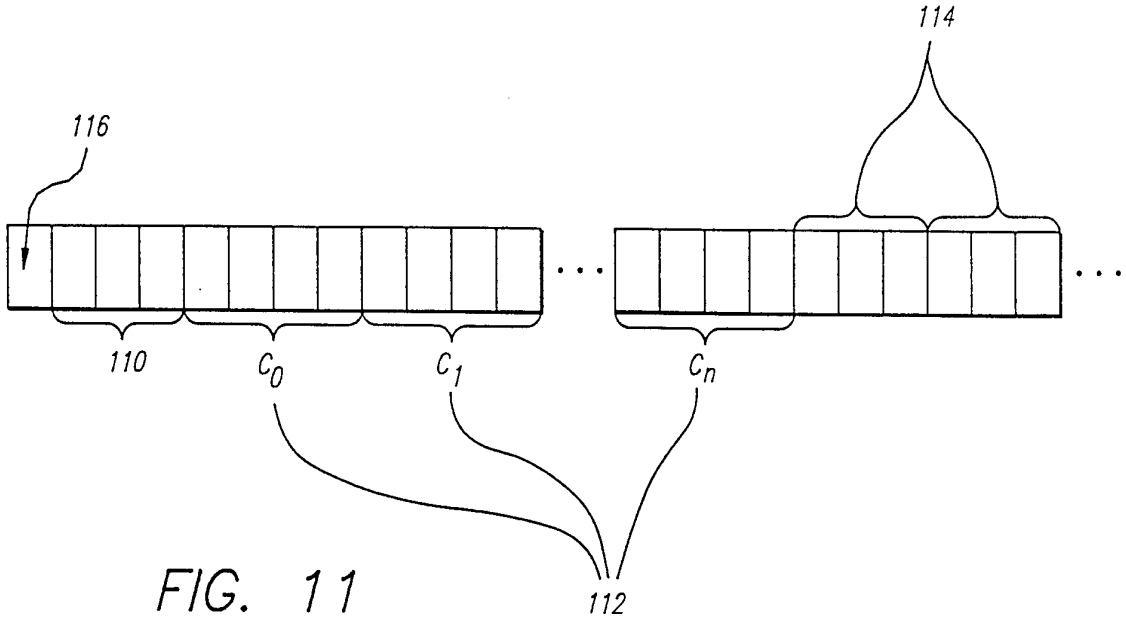

114
116
110
C_0
C_1
C_n
112

FIG. 11

FIG. 10(a)

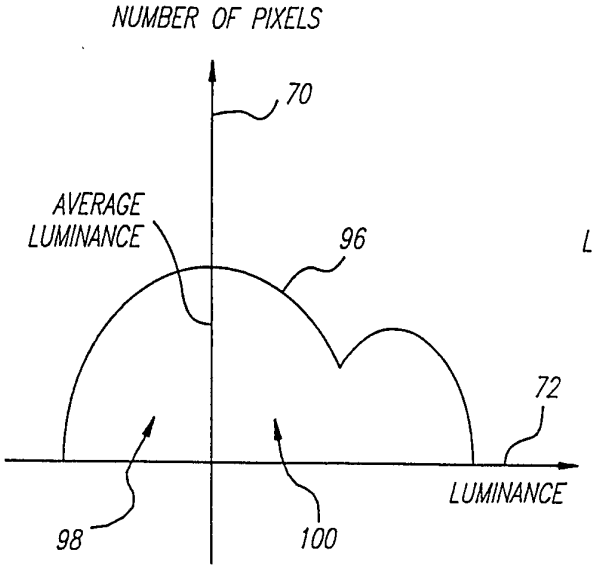
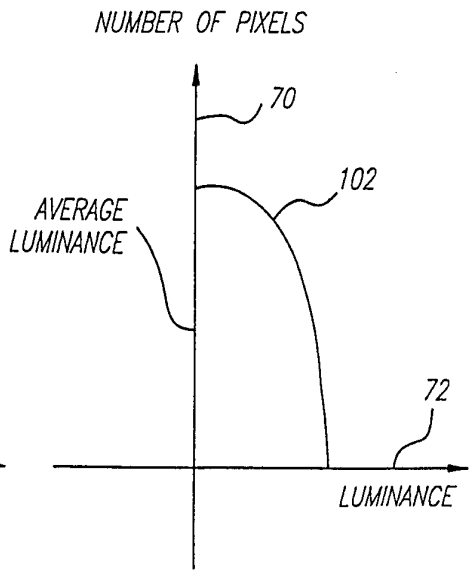


FIG. 10(b)



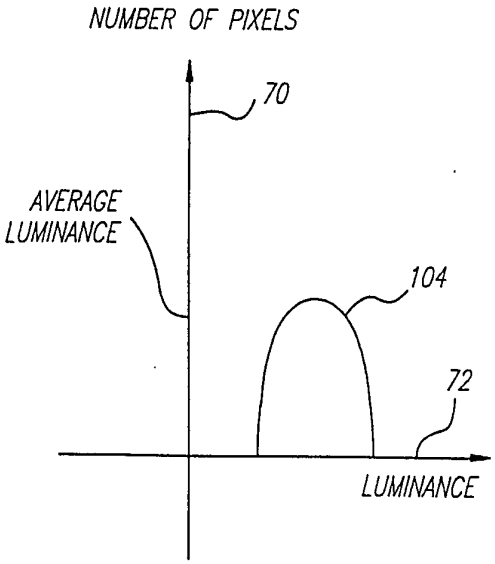


FIG. 10(c)

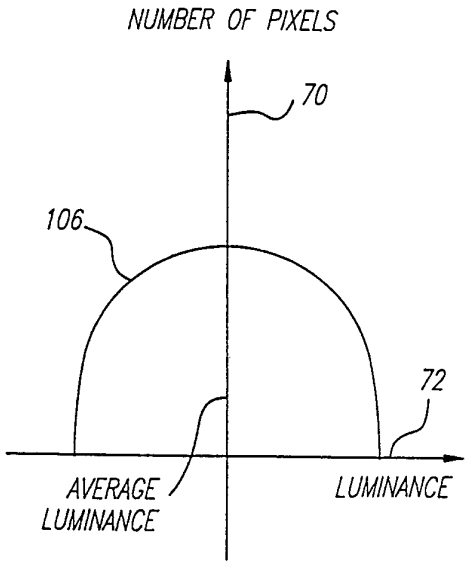


FIG. 10(d)

FIG. 12(a)

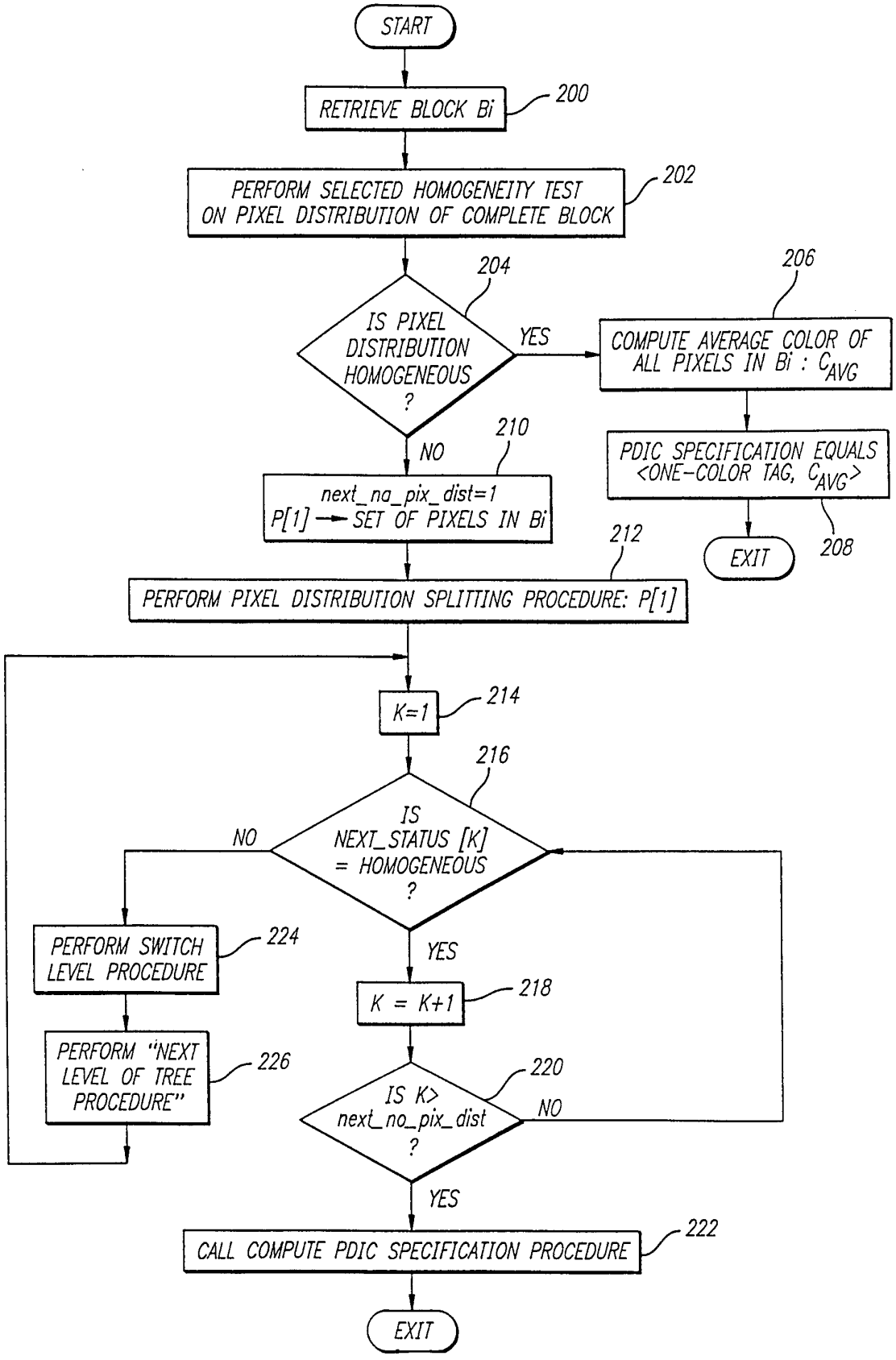
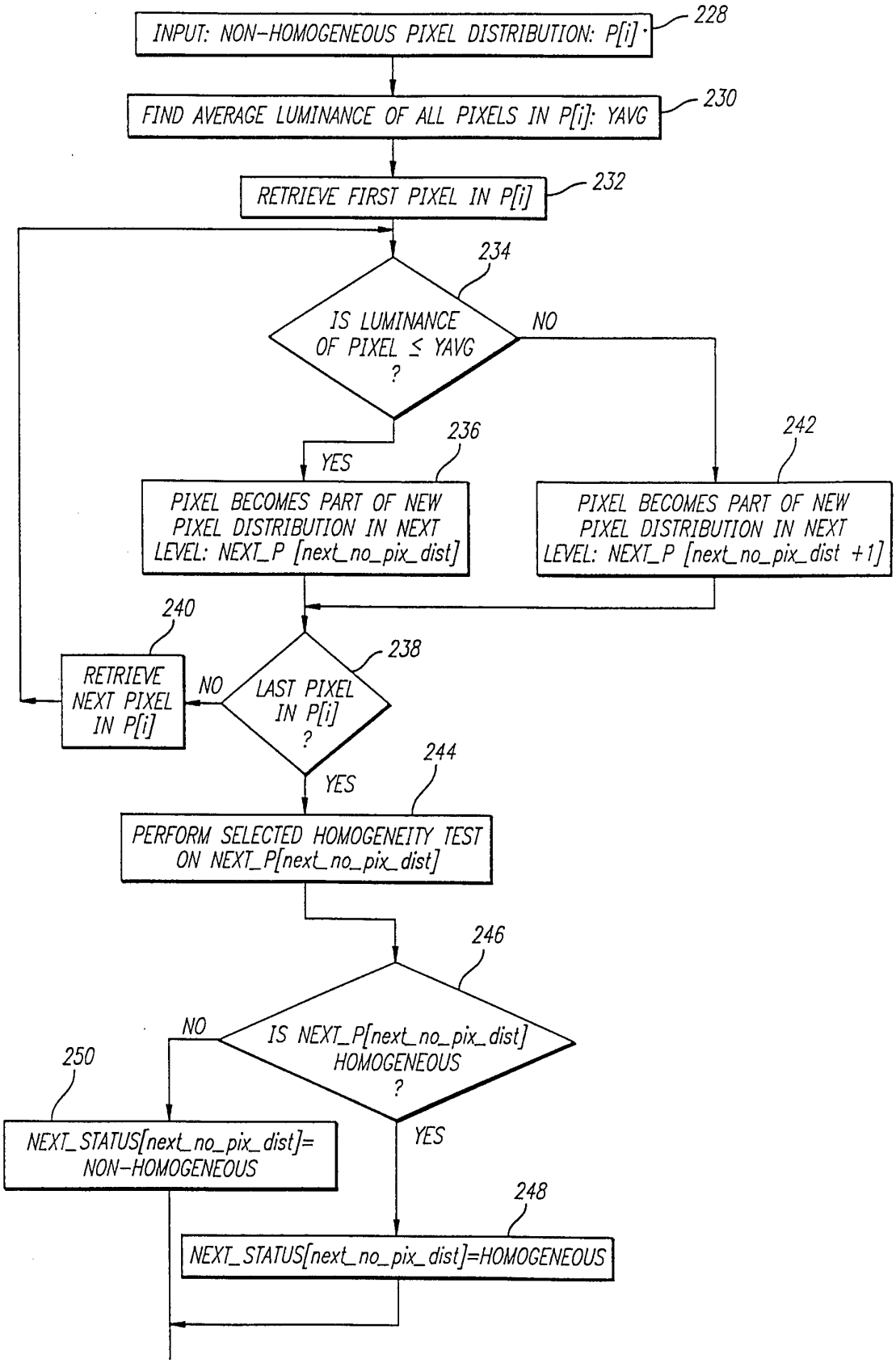

START
RETRIEVE BLOCK Bi
200
PERFORM SELECTED HOMOGENEITY TEST ON PIXEL DISTRIBUTION OF COMPLETE BLOCK
202
IS PIXEL DISTRIBUTION HOMOGENEOUS ?
204
YES
NO
COMPUTE AVERAGE COLOR OF ALL PIXELS IN Bi : C_{AVG}
206
PDIC SPECIFICATION EQUALS <ONE-COLOR TAG, C_{AVG}>
EXIT
208
next_no_pix_dist=1
P[1] → SET OF PIXELS IN Bi
210
PERFORM PIXEL DISTRIBUTION SPLITTING PROCEDURE: P[1]
212
K=1
214
IS NEXT_STATUS [K] = HOMOGENEOUS ?
216
NO
YES
PERFORM SWITCH LEVEL PROCEDURE
224
PERFORM "NEXT LEVEL OF TREE PROCEDURE"
226
K = K+1
218
IS K> next_no_pix_dist ?
220
NO
YES
CALL COMPUTE PDIC SPECIFICATION PROCEDURE
222
EXIT

FIG. 12(b)1


INPUT: NON-HOMOGENEOUS PIXEL DISTRIBUTION: P[i]
228
FIND AVERAGE LUMINANCE OF ALL PIXELS IN P[i]: YAVG
230
RETRIEVE FIRST PIXEL IN P[i]
232
234
IS LUMINANCE OF PIXEL ≤ YAVG ?
NO
YES
236
PIXEL BECOMES PART OF NEW PIXEL DISTRIBUTION IN NEXT LEVEL: NEXT_P [next_no_pix_dist]
242
PIXEL BECOMES PART OF NEW PIXEL DISTRIBUTION IN NEXT LEVEL: NEXT_P [next_no_pix_dist +1]
240
RETRIEVE NEXT PIXEL IN P[i]
NO
238
LAST PIXEL IN P[i] ?
YES
244
PERFORM SELECTED HOMOGENEITY TEST ON NEXT_P[next_no_pix_dist]
246
NO
IS NEXT_P[next_no_pix_dist] HOMOGENEOUS ?
250
NEXT_STATUS[next_no_pix_dist]= NON-HOMOGENEOUS
YES
248
NEXT_STATUS[next_no_pix_dist]=HOMOGENEOUS

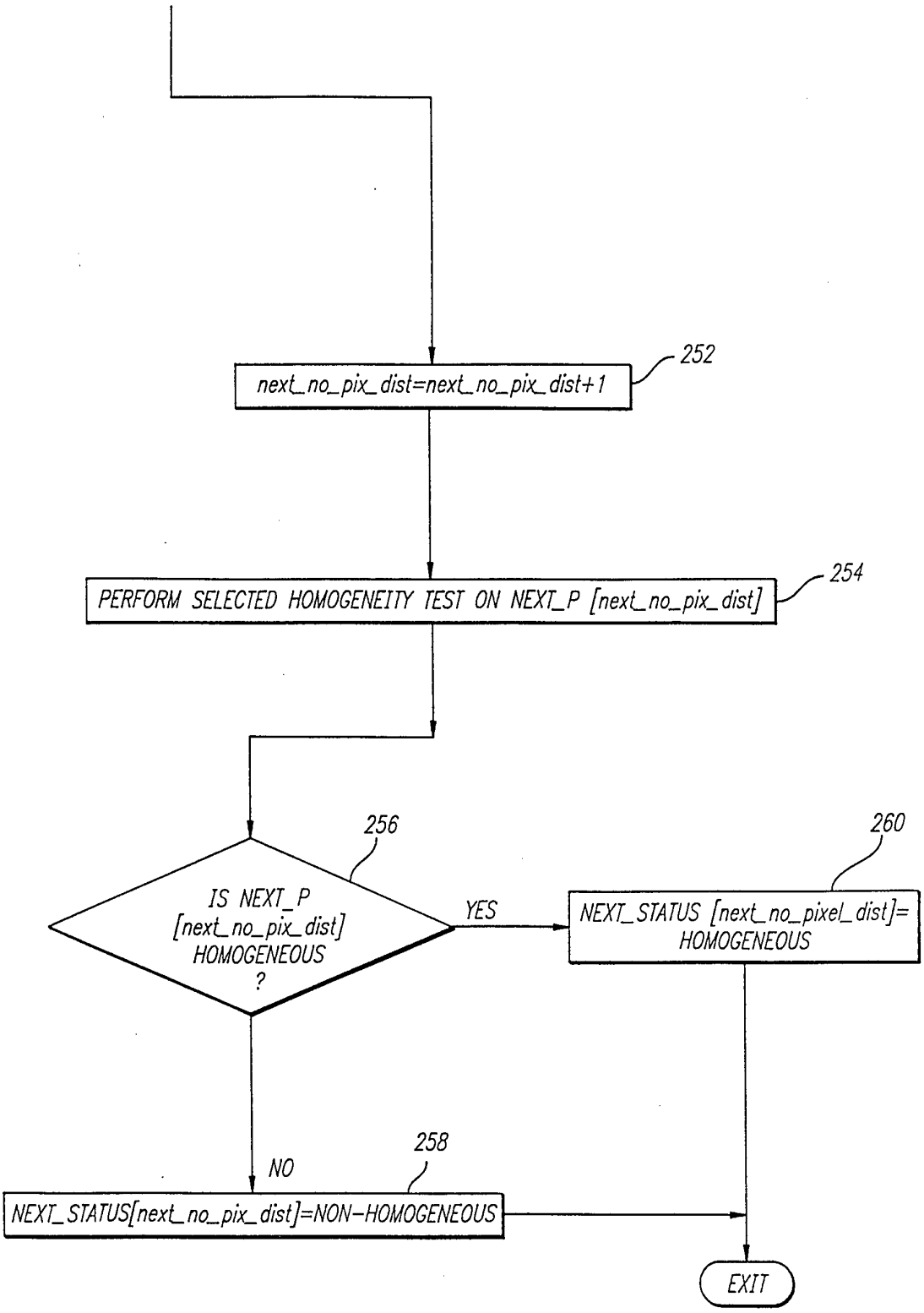

next_no_pix_dist=next_no_pix_dist+1
252
PERFORM SELECTED HOMOGENEITY TEST ON NEXT_P [next_no_pix_dist]
254
IS NEXT_P [next_no_pix_dist] HOMOGENEOUS ?
256
YES
NEXT_STATUS [next_no_pixel_dist]= HOMOGENEOUS
260
NO
258
NEXT_STATUS[next_no_pix_dist]=NON-HOMOGENEOUS
EXIT

FIG. 12(b)2

FIG. 12(c)

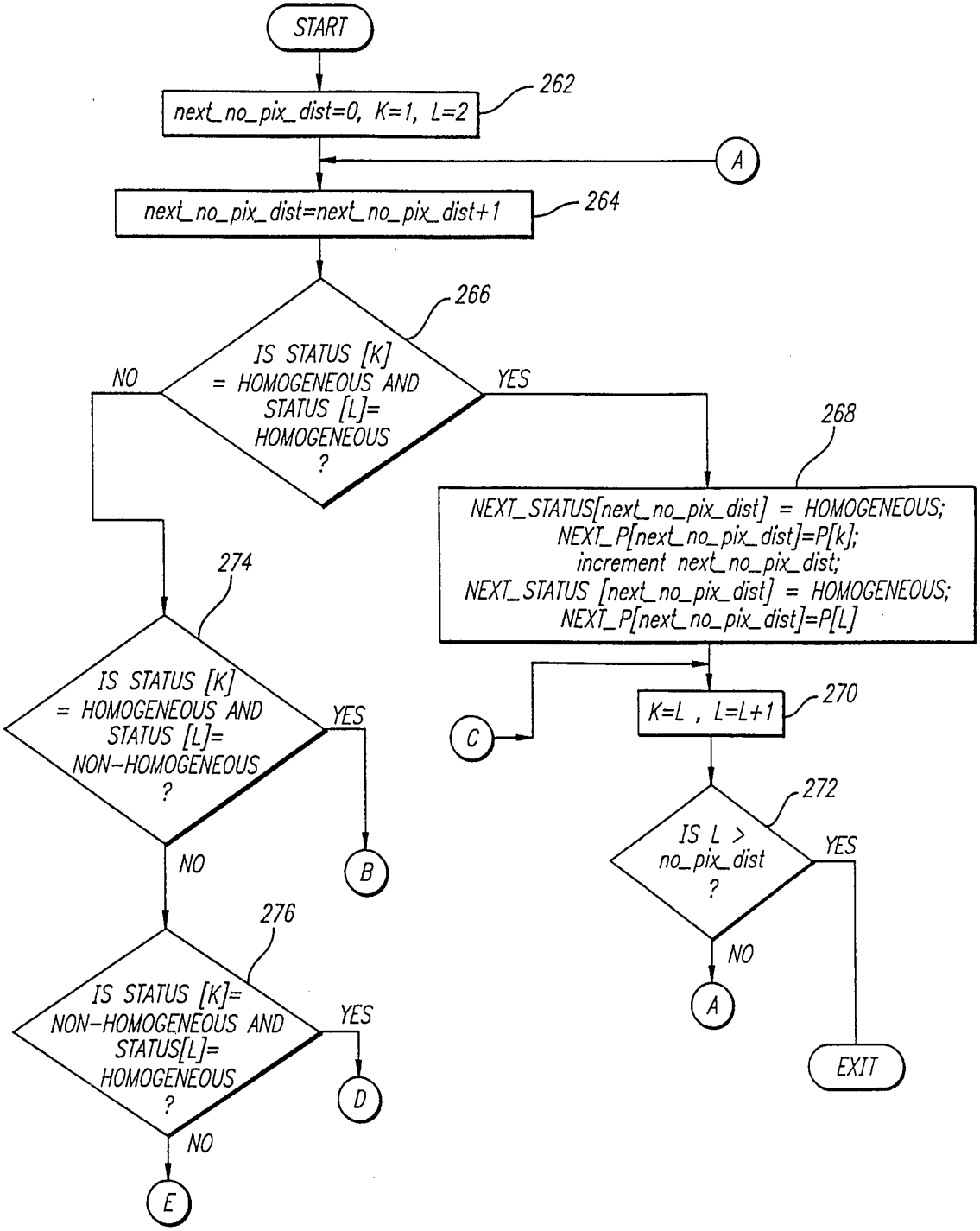

START
next_no_pix_dist=0, K=1, L=2
262
A
next_no_pix_dist=next_no_pix_dist+1
264
266
IS STATUS [K] = HOMOGENEOUS AND STATUS [L]= HOMOGENEOUS ?
NO
YES
268
NEXT_STATUS[next_no_pix_dist] = HOMOGENEOUS;
NEXT_P[next_no_pix_dist]=P[k];
increment next_no_pix_dist;
NEXT_STATUS [next_no_pix_dist] = HOMOGENEOUS;
NEXT_P[next_no_pix_dist]=P[L]
274
IS STATUS [K] = HOMOGENEOUS AND STATUS [L]= NON-HOMOGENEOUS ?
YES
NO
B
C
K=L , L=L+1
270
272
IS L > no_pix_dist ?
YES
NO
A
EXIT
276
IS STATUS [K]= NON-HOMOGENEOUS AND STATUS[L]= HOMOGENEOUS ?
YES
NO
D
E

FIG. 12(d)

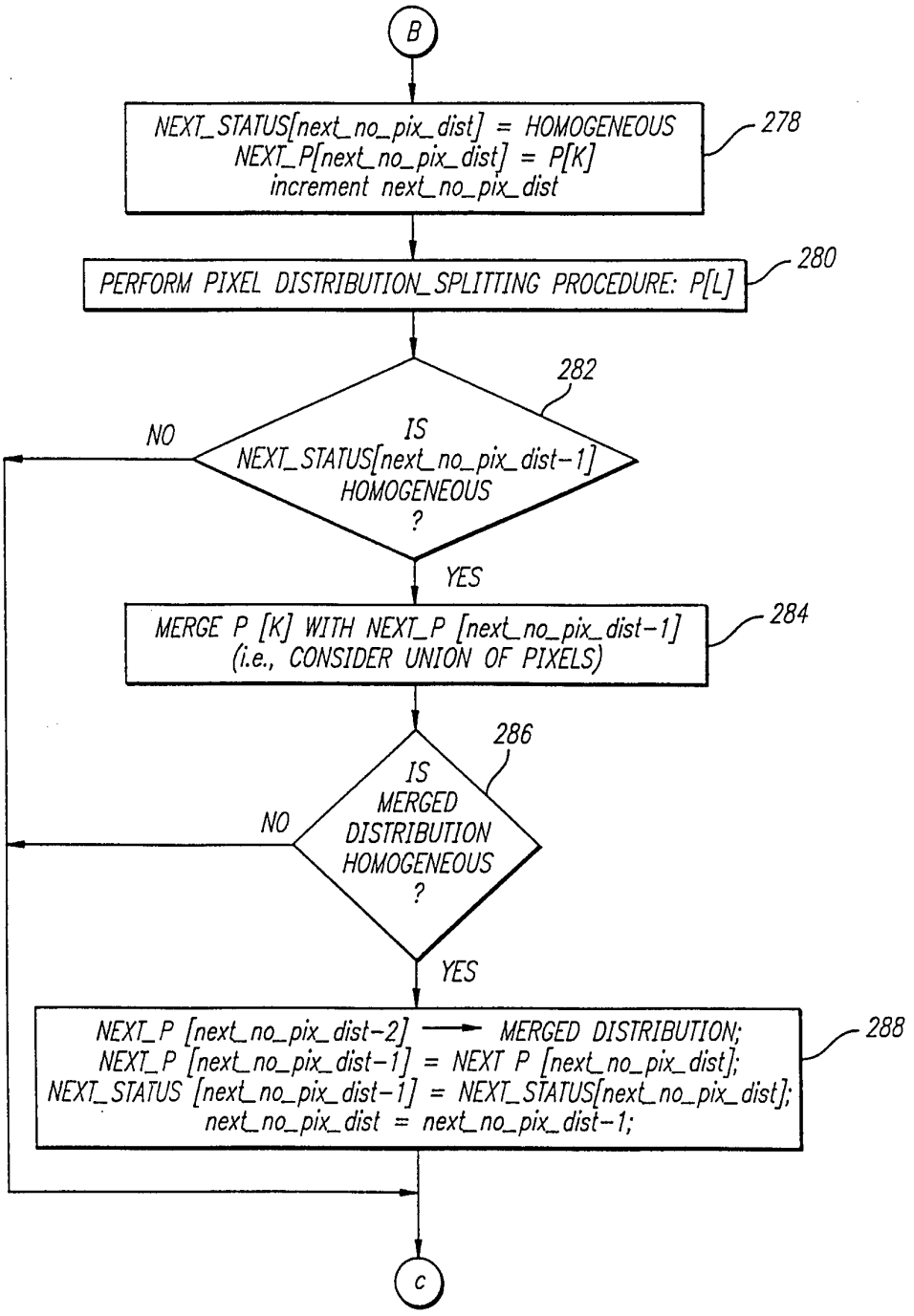

B
NEXT_STATUS[next_no_pix_dist] = HOMOGENEOUS
NEXT_P[next_no_pix_dist] = P[K]
increment next_no_pix_dist
278
PERFORM PIXEL DISTRIBUTION_SPLITTING PROCEDURE: P[L]
280
282
IS NEXT_STATUS[next_no_pix_dist-1] HOMOGENEOUS ?
NO
YES
MERGE P [K] WITH NEXT_P [next_no_pix_dist-1] (i.e., CONSIDER UNION OF PIXELS)
284
286
IS MERGED DISTRIBUTION HOMOGENEOUS ?
NO
YES
NEXT_P [next_no_pix_dist-2] → MERGED DISTRIBUTION;
NEXT_P [next_no_pix_dist-1] = NEXT P [next_no_pix_dist];
NEXT_STATUS [next_no_pix_dist-1] = NEXT_STATUS[next_no_pix_dist];
next_no_pix_dist = next_no_pix_dist-1;
288
C

FIG. 12(e)

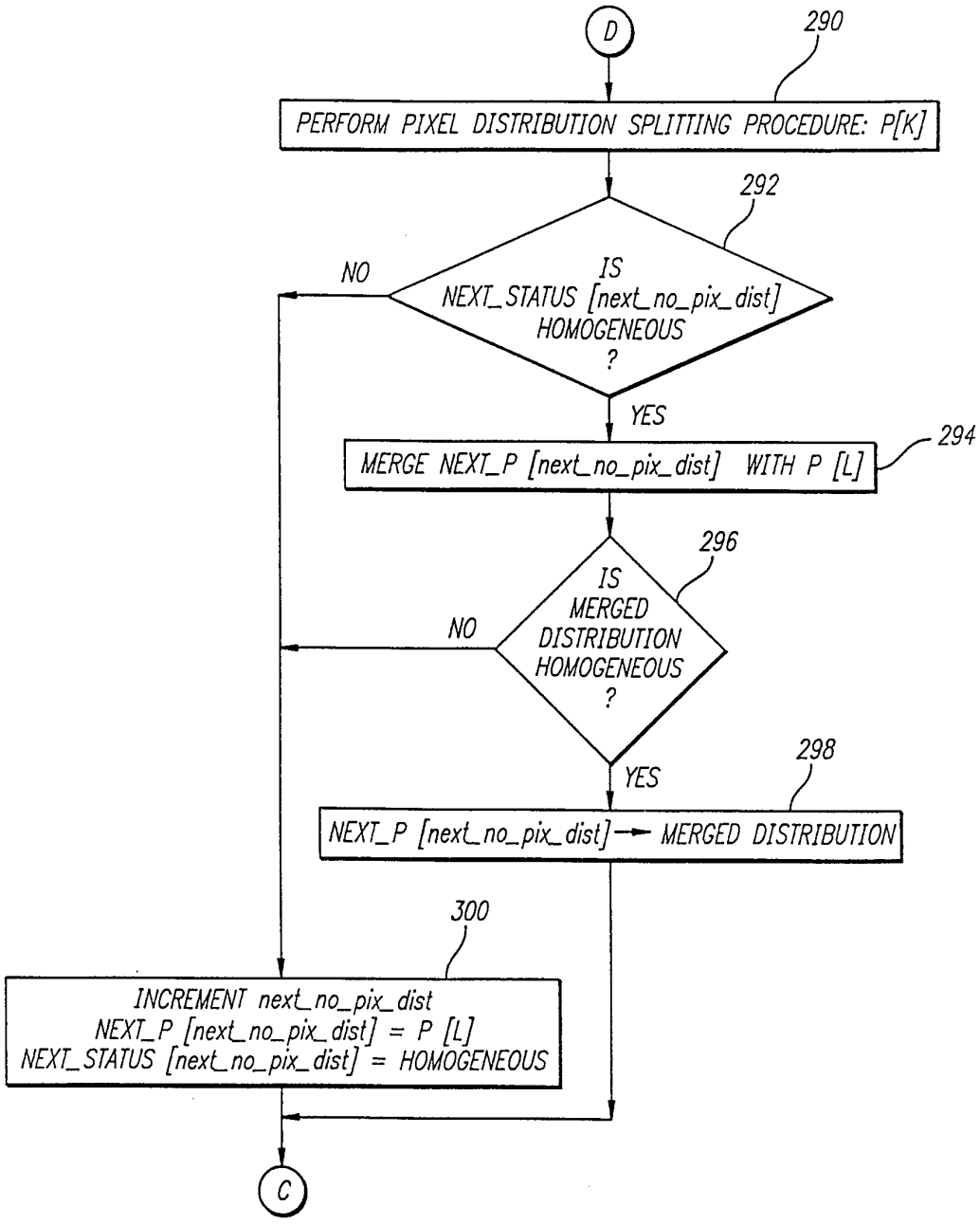

D
290
PERFORM PIXEL DISTRIBUTION SPLITTING PROCEDURE: P[K]
292
IS NEXT_STATUS [next_no_pix_dist] HOMOGENEOUS ?
NO
YES
294
MERGE NEXT_P [next_no_pix_dist] WITH P [L]
296
IS MERGED DISTRIBUTION HOMOGENEOUS ?
NO
YES
298
NEXT_P [next_no_pix_dist] → MERGED DISTRIBUTION
300
INCREMENT next_no_pix_dist
NEXT_P [next_no_pix_dist] = P [L]
NEXT_STATUS [next_no_pix_dist] = HOMOGENEOUS
C

FIG. 12(f)

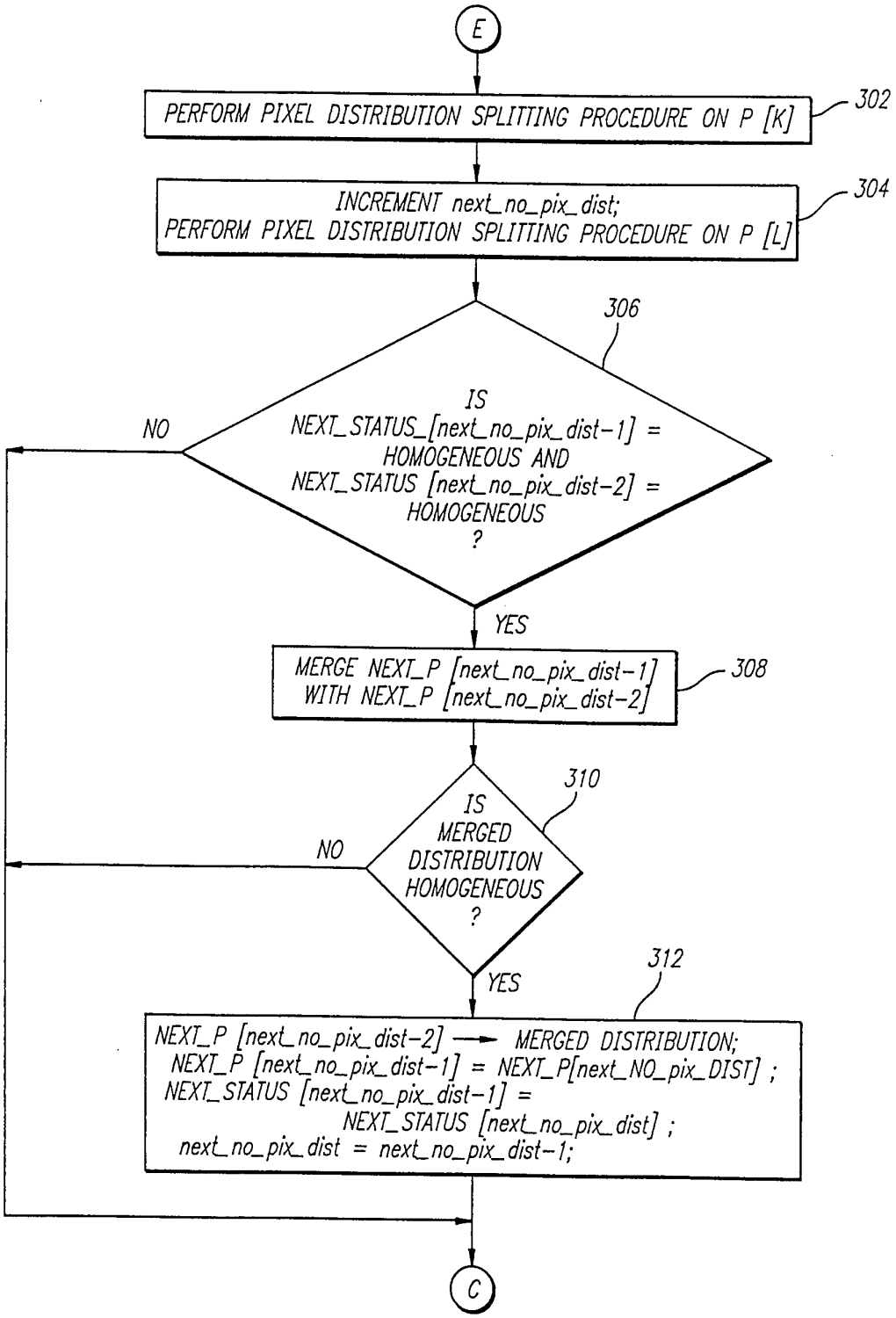

E
PERFORM PIXEL DISTRIBUTION SPLITTING PROCEDURE ON P [K]
302
INCREMENT next_no_pix_dist;
PERFORM PIXEL DISTRIBUTION SPLITTING PROCEDURE ON P [L]
304
306
IS
NEXT_STATUS_[next_no_pix_dist-1] =
HOMOGENEOUS AND
NEXT_STATUS [next_no_pix_dist-2] =
HOMOGENEOUS
?
NO
YES
MERGE NEXT_P [next_no_pix_dist-1]
WITH NEXT_P [next_no_pix_dist-2]
308
310
IS
MERGED
DISTRIBUTION
HOMOGENEOUS
?
NO
YES
312
NEXT_P [next_no_pix_dist-2] → MERGED DISTRIBUTION;
NEXT_P [next_no_pix_dist-1] = NEXT_P[next_NO_pix_DIST] ;
NEXT_STATUS [next_no_pix_dist-1] =
NEXT_STATUS [next_no_pix_dist] ;
next_no_pix_dist = next_no_pix_dist-1;
C

FIG. 12(g)

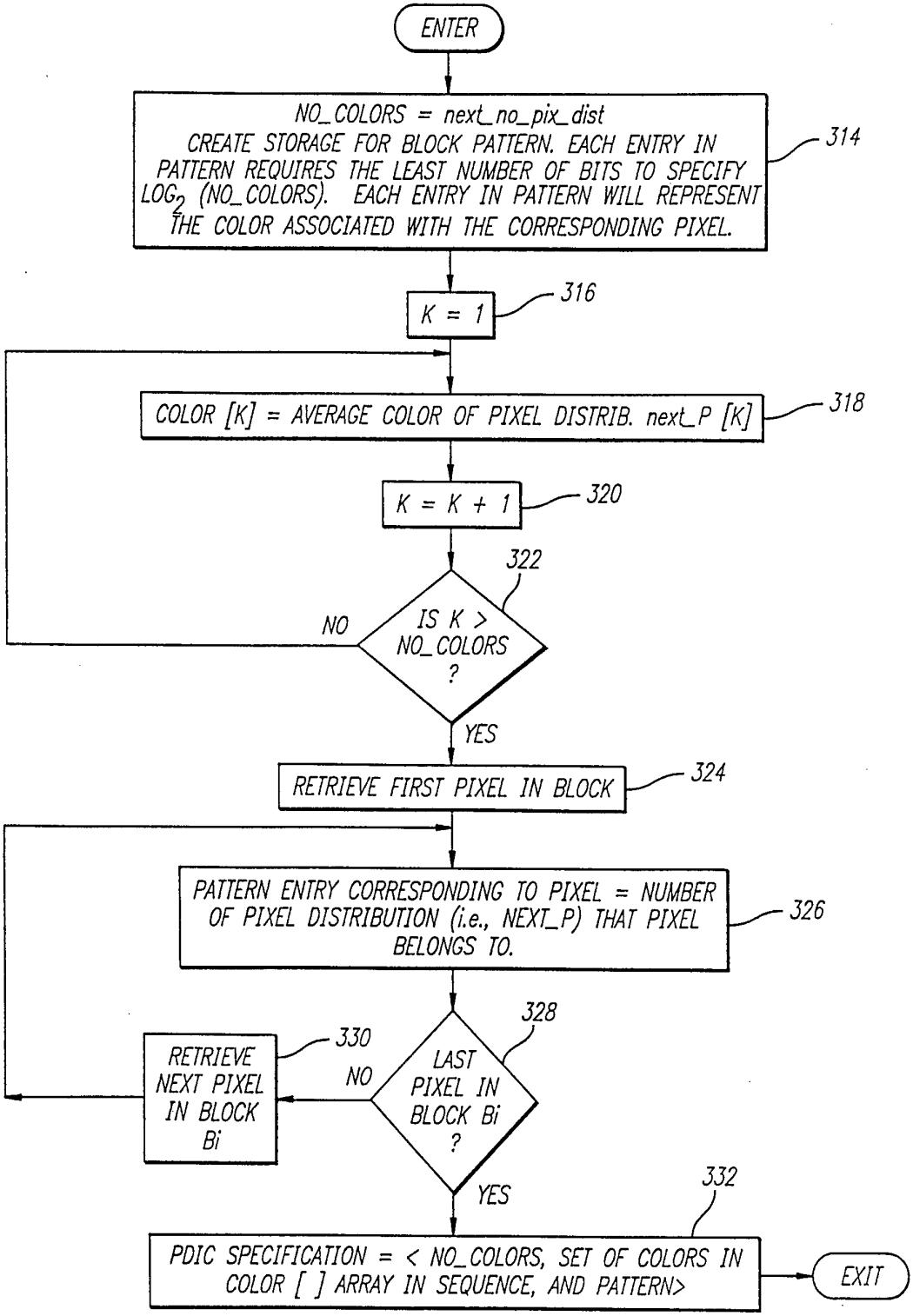

ENTER
NO_COLORS = next_no_pix_dist
CREATE STORAGE FOR BLOCK PATTERN. EACH ENTRY IN PATTERN REQUIRES THE LEAST NUMBER OF BITS TO SPECIFY LOG2 (NO_COLORS). EACH ENTRY IN PATTERN WILL REPRESENT THE COLOR ASSOCIATED WITH THE CORRESPONDING PIXEL.
314
K = 1
316
COLOR [K] = AVERAGE COLOR OF PIXEL DISTRIB. next_P [K]
318
K = K + 1
320
322
IS K > NO_COLORS ?
NO
YES
RETRIEVE FIRST PIXEL IN BLOCK
324
PATTERN ENTRY CORRESPONDING TO PIXEL = NUMBER OF PIXEL DISTRIBUTION (i.e., NEXT_P) THAT PIXEL BELONGS TO.
326
328
LAST PIXEL IN BLOCK Bi ?
NO
330
RETRIEVE NEXT PIXEL IN BLOCK Bi
YES
332
PDIC SPECIFICATION = < NO_COLORS, SET OF COLORS IN COLOR [ ] ARRAY IN SEQUENCE, AND PATTERN>
EXIT

FIG. 12(h)

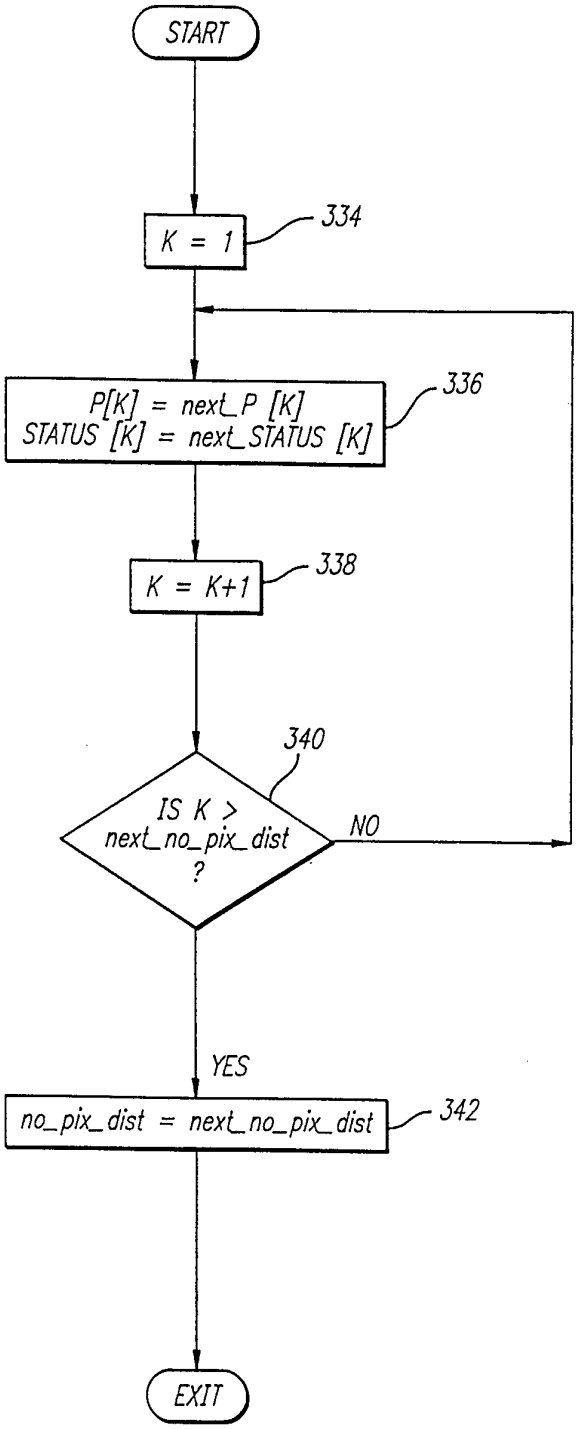

START
K = 1
334
P[K] = next_P [K]
STATUS [K] = next_STATUS [K]
336
K = K+1
338
340
IS K > next_no_pix_dist ?
NO
YES
no_pix_dist = next_no_pix_dist
342
EXIT

FIG. 13

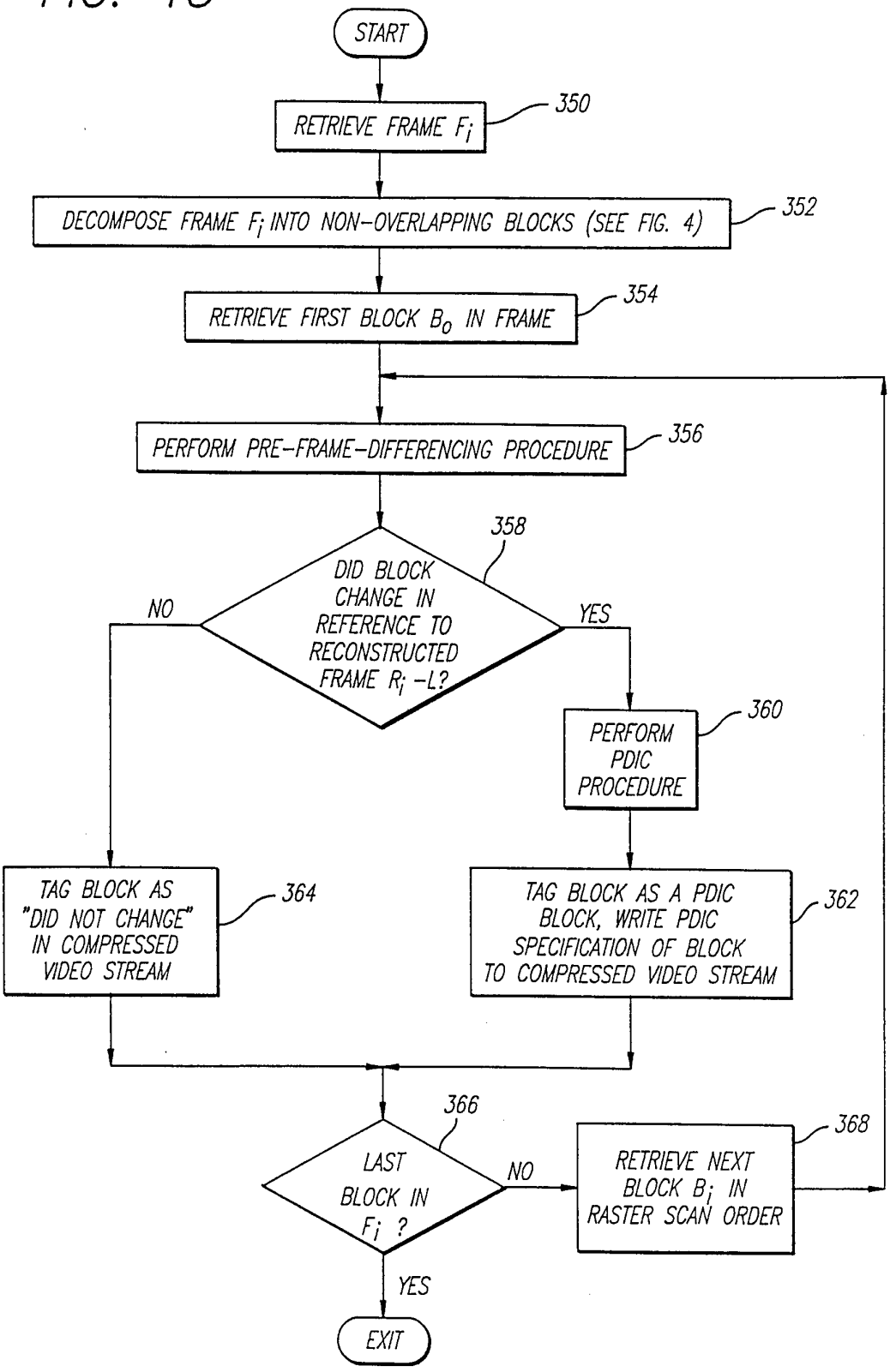
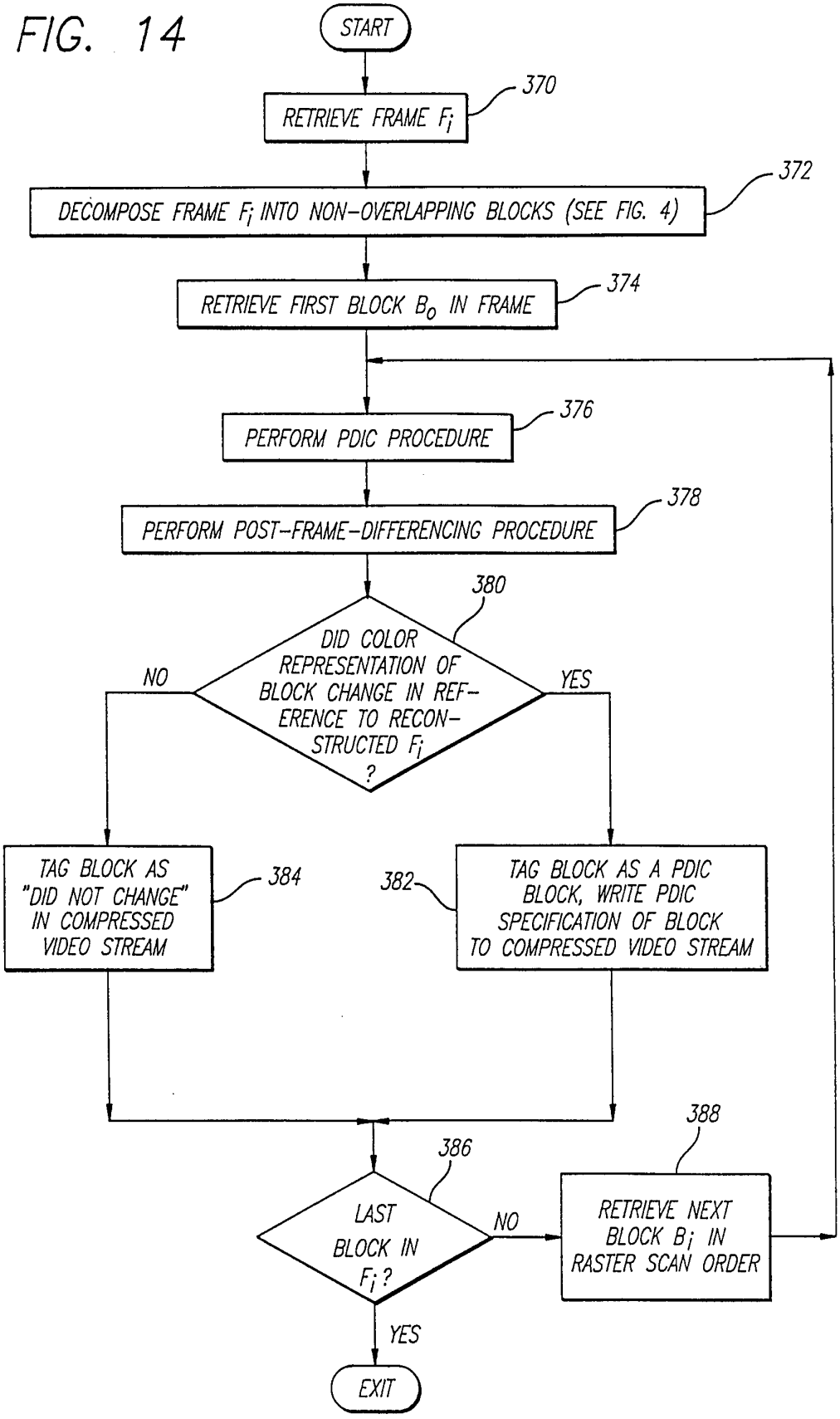

START
RETRIEVE FRAME F_i
350
DECOMPOSE FRAME F_i INTO NON-OVERLAPPING BLOCKS (SEE FIG. 4)
352
RETRIEVE FIRST BLOCK B_0 IN FRAME
354
PERFORM PRE-FRAME-DIFFERENCING PROCEDURE
356
DID BLOCK CHANGE IN REFERENCE TO RECONSTRUCTED FRAME R_i -L?
358
NO
YES
PERFORM PDIC PROCEDURE
360
TAG BLOCK AS "DID NOT CHANGE" IN COMPRESSED VIDEO STREAM
364
TAG BLOCK AS A PDIC BLOCK, WRITE PDIC SPECIFICATION OF BLOCK TO COMPRESSED VIDEO STREAM
362
LAST BLOCK IN F_i ?
366
NO
RETRIEVE NEXT BLOCK B_i IN RASTER SCAN ORDER
368
YES
EXIT

FIG. 14


START
RETRIEVE FRAME F_i
370
DECOMPOSE FRAME F_i INTO NON-OVERLAPPING BLOCKS (SEE FIG. 4)
372
RETRIEVE FIRST BLOCK B_0 IN FRAME
374
PERFORM PDIC PROCEDURE
376
PERFORM POST-FRAME-DIFFERENCING PROCEDURE
378
DID COLOR REPRESENTATION OF BLOCK CHANGE IN REFERENCE TO RECONSTRUCTED F_i ?
380
NO
YES
TAG BLOCK AS "DID NOT CHANGE" IN COMPRESSED VIDEO STREAM
384
382
TAG BLOCK AS A PDIC BLOCK, WRITE PDIC SPECIFICATION OF BLOCK TO COMPRESSED VIDEO STREAM
388
386
LAST BLOCK IN F_i ?
NO
RETRIEVE NEXT BLOCK B_i IN RASTER SCAN ORDER
YES
EXIT

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/US 95/05674

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N11/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,5 046 119 (HOFFERT ERIC M ET AL) 3 September 1991 see column 1, line 19 - column 2, line 3 see column 4, line 54 - column 6, line 55; claim 1; figure 3	1,3,4,7, 15,17
A	PATENT ABSTRACTS OF JAPAN vol. 18 no. 417 (P-1781) ,4 August 1994 & JP,A,06 124343 (TOPPAN PRINTING CO.,LTD.) 6 May 1994, see abstract	1,3,15, 17
A	FR,A,2 628 864 (ETAT FRANCAIS) 22 September 1989 see page 2, line 17 - page 311 see page 4, line 26 - line 34	1,15

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 August 1995	29. 08. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Fuchs, P

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/US 95/05674

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-5046119	03-09-91	JP-A- 4270473	25-09-92
		US-A- 5047853	10-09-91
FR-A-2628864	22-09-89	NONE	