



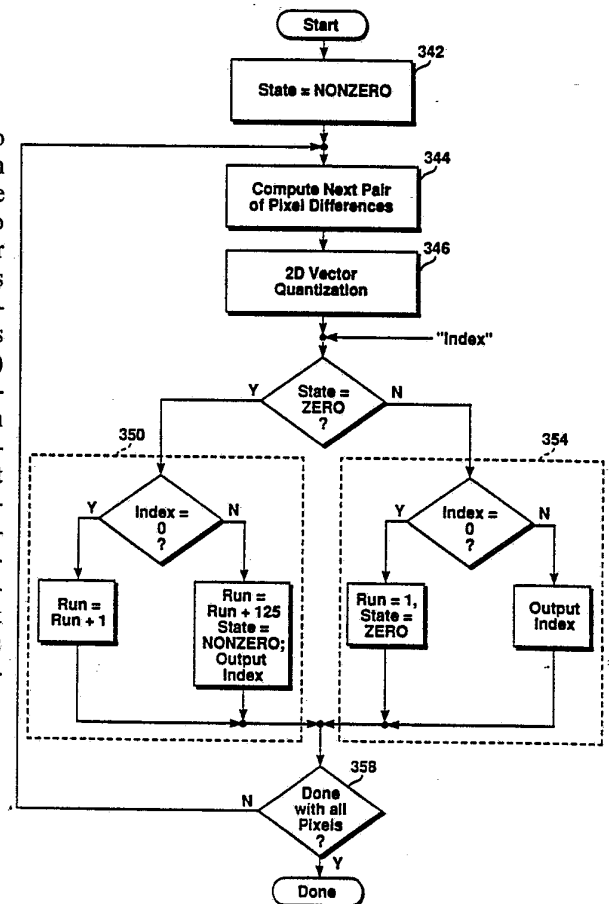
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(54) Title: METHOD AND APPARATUS FOR REAL TIME COMPRESSION AND DECOMPRESSION OF A DIGITAL MOTION VIDEO SIGNAL

(57) Abstract

A bitstream (100) representative of at least one digital video image is decoded in real time by providing a code-book index from the bitstream (110), applying the code-book index to an index table to determine an index value (120), and comparing the index value to a first predetermined threshold (130). If the index value is greater than the predetermined threshold, then at least one current pixel is determined by copying a corresponding previous pixel into the location of at least one current pixel (140); otherwise the index value is applied to a vector table to determine at least one vector value (150) and a current pixel is determined from the vector value and a corresponding previous pixel (160). A digital video image is encoded in real time by selecting at least one pixel for encoding and determining at least one difference value between the selected pixel and at least one corresponding previous pixel (344). An index value corresponding to the location in a first table of the difference value is calculated (346). If the index value is equal to a first predetermined value then a run-length counter is incremented by a second predetermined value and the process is repeated until the index value is not equal to the first predetermined value. The run-length counter is then encoded. If the index value is not equal to the first predetermined value then the index value is encoded.



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METHOD AND APPARATUS FOR REAL TIME COMPRESSION AND
DECOMPRESSION OF A DIGITAL MOTION VIDEO SIGNAL

Field Of The Invention

This invention relates to video signal processing generally and particularly to systems for providing a compressed digital video signal representative of a full color video signal.

Background Of The Invention

In real time video systems, compression and decompression are typically done using the same or similar hardware at roughly the same speed. Real time video systems have often required hardware that is too expensive for a single user, or such systems have sacrificed picture quality in favor of lower cost hardware. This problem has been bypassed by the use of presentation level video systems where the compression is performed on expensive hardware, but the decompression is done by low cost hardware. This solution works only in situations where the single-user system needs only to playback compressed video which has been prepared ahead of time.

It is an object of the present invention to provide a system for compressing and decompressing motion video in real time which may operate on lower cost hardware while maintaining acceptable picture quality.

Further objects and advantages of the invention will become apparent from the description of the invention which follows.

Summary Of The Invention

A method and apparatus for real time compression and decompression of a digital motion video signal is disclosed. According to the present invention, a bitstream representative of at least one digital video image is decoded in real time by first providing a code-book index from the bitstream. The code-book index is applied to an index table to determine an index value which is compared to a first predetermined threshold. If the index value is greater than the predetermined threshold, then at least one current pixel is determined by copying a corresponding previous pixel into the location of at least one current pixel; otherwise, the index value is applied to a vector table to determine at least one vector value and at least one current pixel is determined from the vector value and a corresponding previous pixel.

In accordance with the present invention, at least one digital video image is encoded in real time by selecting at least one pixel for encoding and determining at least one difference value between the selected pixel and at least one corresponding previous pixel. An index value corresponding to the location in a first table of the difference value is calculated. If the index value is equal to a first predetermined value then a run-length counter is incremented by a second predetermined value and the process is repeated until the index value is not equal to the first predetermined value. The run-length counter is then

encoded. If the index value is not equal to the first predetermined value then the index value is encoded.

Brief Description Of The Drawings

Figure 1 is a flow diagram illustrating the operation of a decoder according to a preferred embodiment of the present invention.

Figure 2A shows the use of a corresponding previous pixel to perform intra-frame decoding in accordance with a preferred embodiment of the present invention.

Figure 2B shows the use of a corresponding previous pixel to perform inter-frame decoding in accordance with a preferred embodiment of the present invention.

Figure 3 is a flow diagram illustrating the operation of an encoder according to a preferred embodiment of the present invention.

Figure 3A is a flow diagram illustrating the vector quantization and run-length encoding procedures of the encoder of Figure 3.

Figure 3B is a flow diagram illustrating the Huffman encoder of Figure 3.

Figure 4A is a flow diagram illustrating a video compression system according to the present invention.

Figure 4B is a flow diagram illustrating a video decompression system according to the present invention.

Detailed Description Of The Preferred Embodiment

Referring now to Figure 1, there is shown a flow diagram illustrating the operation of a decoder for decoding a bitstream 100 according to a preferred embodiment of the present invention. Bitstream 100 represents a motion video sequence of one or more images which have been encoded in real time. Encoded data from bitstream 100 is applied to Huffman decoder 110 to derive a code-book index representing the position of a code-word within a lexicographically-ordered list of codewords. The code-book index is then used as an entry point to determine an index value from look-up table 120. Comparing means 130 are provided for comparing the index value to a predetermined threshold. If the index value is greater than the predetermined threshold, then copying means 140 determines at least one current pixel by copying a corresponding previous pixel into the location of a current pixel. In a preferred embodiment, copying means 140 calculates the amount that the index value exceeds the predetermined threshold, and then determines that number of current pixels by copying that number of corresponding previous pixels into respective current pixel locations. If the index value is not greater than the predetermined threshold, then the index value is used as an entry point to determine at least one vector value from vector table 150. Means 160 then determines at least one current pixel from a vector value and a corresponding previous pixel. In the preferred embodiment, means 160 uses the index value to determine two vector values which are adjacent in vector table 150. The two

vector values are then used by means 160 to determine two adjacent current pixels from two corresponding previous pixels.

The preferred embodiment of the present invention is intended for compression of 8-bit planes of an image. The present invention may also be used with 9-bit YUV images, and other image formats, including 12-bit image formats, may also be used. In the preferred embodiment, the same compression and decompression process steps are applied to each color component of each image in a sequence. As used below, the term image refers to a single color component of an image.

In the preferred embodiment, each image in the sequence is encoded as either a still image or by using inter-frame differences. During the encoding of an image, each pixel in the image is subtracted from a corresponding previous pixel and the differences are encoded. As shown in Figure 2A, if the image (200) is being encoded as a still (intra-frame encoding), the corresponding previous pixel (210) is preferably the pixel directly above the current pixel being encoded (220). As shown in Figure 2B, if the image (240) is encoded using inter-frame differences, the corresponding previous pixel (232) is preferably the pixel in the previous image (230) located in the same position (in the bitmap) as the current pixel being encoded (234). In either case, there is a difference image (whose values tend to cluster around zero) which is encoded. Difference images are preferably encoded using 2-D vector quantization, with some

run-length encoding added to help encode large areas of zeros efficiently.

In the preferred embodiment, bitstream 100 includes the following fields for each frame in a sequence: StillFlag, DataSize, ImageHeight, ImageWidth, Flags, VectorSet, a Huffman table descriptor for the image, and Huffman encoded data for the Y, V, U planes. The StillFlag field indicates whether the image is a still, DataSize indicates the size of the bitstream in bits, and ImageHeight and ImageWidth give the size of the decoded image in pixels. The Flags field indicates whether the data in the bitstream represents an image that has been encoded at full resolution, half vertical resolution, half horizontal resolution, or half vertical and half horizontal resolution. Such half resolution images may be obtained prior to encoding by subsampling the full resolution image in one or both dimensions. In the preferred embodiment, an image for encoding is considered to be at full resolution if it is ImageHeight pixels high and ImageWidth pixels wide; it is considered to be at half vertical resolution if it is ImageHeight pixels high and ImageWidth/2 pixels wide; it is considered to be at half horizontal resolution if it is ImageHeight/2 pixels high and ImageWidth pixels wide; and it is considered to be at half vertical and half horizontal resolution if it is ImageHeight/2 pixels high and ImageWidth/2 pixels wide.

In the preferred embodiment, the VectorSet field is a number from 0 to 7 which is used to select one of eight vector

sets to use for decoding an image. Each of the vector sets contains 128 ordered pairs which may be thought of as points defined by X and Y coordinates. In all the vector sets, the ordered pairs are clustered about the point (128, 128); however, the average distance between the ordered pairs and the center point (128, 128) varies among the vectors sets. In VectorSet 0, the ordered pairs are closely clustered about (128, 128). VectorSet 0 thus corresponds to the lowest quantization level. As one moves from VectorSet 0 to VectorSet 7, the ordered pairs cluster less closely around (128, 128). VectorSet 7 thus corresponds to the highest quantization level.

The eight vector sets used in the preferred embodiment of the present invention are attached hereto as Appendix I. In the preferred embodiment, the vectors have arithmetic values in the range -128 to 127. The vector values shown in Appendix I have 128 added to them, so that they are in the range 0 to 255. Other vector sets may be used without departing from the spirit of the present invention.

In the preferred embodiment, the value of the VectorSet field may vary from image to image, thus allowing the encoder to vary the quantization level between images. In this embodiment, the vector set selected by the VectorSet field is used to decode the Y component image. The vector set selected by the value VectorSet/2 is used for the U, V components. Better quantization is normally required for encoding the U, V component images, since these components are typically subsampled spatially. In an alternate

embodiment, a single vector set may be used to encode and decode all images in a sequence.

A Huffman table descriptor for each image is also included in the format of bitstream 100. The Huffman table is preferably of the form shown in Table I below:

```

0[xx...x]
10[xx...x]
110[xx...x]
1110[xx...x]
11110[xx...x]
111110[xx...x]
1111110[xx...x]
11111110[xx...x]

```

Table I

Byte K in the Huffman table descriptor indicates how many "x bits" there are in row K of the above table. The Huffman decoding operation collects bits from the bitstream one at a time until a code word in a codebook is recognized. Huffman decoder 110 returns a codebook index representing the position of a code-word within a lexicographically-ordered list of code words. Following the above header information in bitstream 100 is the Huffman encoded data describing the Y plane. Data for the V and U planes immediately follows the Y plane data. In the preferred embodiment, the V and U data describe a bitmap which is 1/4 the size horizontally and 1/4 the vertically of the Y bitmap. The final result is a YUV 4:1:1 image which may be displayed directly by a display processor, or converted to some other display format if desired.

Decoding Procedure

The decoding procedure for a still image can be described by the c-language pseudo code in Table II below. In the pseudo code, the function huffdec() performs a huffman decode operation as described above and returns an unsigned integer representing the code-book index:

Define

```
Width = ImageWidth, divided by 2 depending on the
      value of Flags
Height = ImageHeight, divided by 2 depending on
      the value of Flags
```

Then:

```
unsigned char *curr,*prev;
unsigned int *vec;

for (x=0; x<Width; x++) // Fill first line with 128's
    bitmap[0][x] = 128;

for (y=0; y<Height; y++) // for each line of image
// point to beginning of current line and previous line
    curr = &bitmap[y][0];
    prev = &bitmap[y - (y != 0)][0];

    for (x=0; x<Width; x+=2) // for each pair of //
pixels
        k = index[huffdec()];

// Now do either a run-length of 0's or a single vector,
// depending on the value of k.
    if (k > 256) // run-length of 0's?
        for (i=0; i<k-256; i++)
            *curr++ = *prev++;
        x += k-258;

    else // apply a single vector
        vec = vectors + k;
```

```
*curr++ = clamp (*prevv++ + *vecc++);
*curr++ = clamp (*prevv++ + *vecc++);
```

where:

'vectors' is a pointer to the vector set to use for this image, and index[] is the following array:

```
index[] =
  2,  4, 258,  6,  8, 260, 10, 12,
262, 264, 14, 16, 266, 18, 20, 22,
 24, 26, 28, 268, 30, 32, 270, 272,
 34, 36, 38, 40, 274, 42, 44, 276,
 46, 48, 278, 50, 52, 280, 54, 56,
282, 58, 60, 284, 62, 64, 286, 66,
 68, 288, 70, 72, 74, 76, 78, 80,
 82, 84, 86, 88, 90, 92, 94, 96,
 98, 100, 102, 104, 106, 108, 110, 112,
114, 116, 118, 120, 122, 124, 126, 128,
130, 132, 134, 136, 138, 140, 142, 144,
146, 148, 150, 152, 154, 156, 158, 160,
162, 164, 166, 168, 170, 172, 174, 176,
178, 180, 182, 184, 186, 188, 190, 192,
194, 196, 198, 200, 202, 204, 206, 208,
210, 212, 214, 216, 218, 220, 222, 224,
226, 228, 230, 232, 234, 236, 238, 240,
242, 244, 246, 248, 250, 252, 254,
```

and clamp(x) is a function defined as follows:

```
clamp(x) = 0      if x < 128
           x-128  if 128 >= x < 384
           255   if x >= 384
```

Table II

After executing the above procedure, the decoder then scales the image up horizontally and/or vertically by a factor of two, if requested to by the Flags field in the header.

The decoding procedure for an inter-frame (non-still) image is similar to that described in Table II, and is obtained by deleting the first 2 lines of code, and changing the line

```
prev = &bitmap[y - (y != 0)][0];
```

to

```
prev = &prev_bitmap[y][0];
```

Scalability

By manipulating the Flags and StillPeriod parameters in the encoder, it is possible to create real time video files which can be scalably decoded; that is, yielding reasonable-quality playback on a typical micro-processor (for example, a 386/486 class processor), and better quality on a higher-performance video signal processor chip (for example, a DVI i750 chip). In a preferred embodiment, real time video files which can be scalably decoded are created by setting Flags so that half vertical and half horizontal resolution is selected. The decoder would therefore normally be expected to scale up the image by 2x both vertically and horizontally after decoding. According to the present invention, if a sequence of 256x240 images is compressed at 128x120 resolution, it can be decompressed and displayed as a sequence of 128x120 images on a typical micro-processor. By opting not to interpolate the 128x120 images back up to 256x240 images, a typical micro-processor can be used to reproduce image sequences encoded in real time with a reasonable degree of quality. The image quality level can be improved through the use of a higher-performance

video signal processor which reproduces the sequence by decoding and then interpolating back up to 256x240 images. Thus, the same encoded sequence can be reproduced at different quality levels depending on the limitations of the decompression hardware. Another aspect of real time video files which can be scalably decoded would allow a typical micro-processor system to use a VGA for display whereas a video signal processor system may use a 24-bit-color i750DB display. The micro-processor system might choose to display in monochrome to avoid messy YUV-to-VGA-clut conversion.

In a still further aspect of scalability, during compression a user may set the parameter "StillPeriod" to P, thus requiring every Pth image to be encoded as a still. The other images may then be encoded using inter-frame differences. P can typically be set quite small without adversely affecting image quality. By compressing a sequence with P=3, the processing requirements for a micro-processor type system can be reduced without adversely affecting image quality. For example, decompressing and displaying still images using a 386/486 processor typically yields a 10fps display. This frame rate can be increased smoothly from 10fps to 30fps if P=3.

Encoding Procedure

Referring now to Figure 3, there is shown an overall flow diagram for encoding an image in real time according to a preferred embodiment of the present invention.

The first step is to determine whether to encode the image as an intra-frame (a still image) or an inter-frame (an image encoded relative to the previous image in the sequence). For this purpose, a user parameter called StillPeriod is used. The user sets StillPeriod to a given value (K) to force every Kth image to be encoded as a still (INTRA) image. For efficiency of encoding, an encoder may choose to use an INTRA frame even for images in between every-Kth image. For example, if there is a scene cut or if the video enters a period of very high motion, then an intra-frame image will be more efficient to encode than an inter-frame, because the correlation between adjacent images will be too small to be advantageous.

As shown in Figure 3, means 310 first computes the absolute difference (ABSDIF) between frame N and the previous frame (N-1). This involves summing the absolute value of the differences between all pixels in the two images. For efficiency of computation it is preferable to only use a subset of the pixels in the two images for the purpose of comparison. This provides as nearly an accurate measure of the difference between the two images at a greatly reduced computational cost. After this computation, means 320 (i) compares the absolute difference between frame N and a previous frame N-1 with a predetermined threshold, and (ii) computes the value of $N \bmod \text{StillPeriod}$. If means 320 determines (i) that the absolute difference is greater than the predetermined threshold or (ii) that $(N \bmod \text{StillPeriod})$ is zero, then the frame type is set to INTRA by means 325.

Otherwise, the frame type is set to INTER by means 330. In alternate embodiments, parameters other than the absolute difference between all pixels in frames N and N-1 may be used in determining how to set the frame type. For example, the mean-square error between pixels in frames N and N-1 or the relative difference between such pixels may be used.

After determining whether to encode as an INTRA or INTER image, means 340a next computes the pixel differences which are to be encoded. As described in the discussions of Figures 2A, 2B above, if the image is an INTRA, each pixel has subtracted from it the value of the pixel immediately above it in the same image. (For the top row, a "phantom value" of 128 is used for these pixels.) If the image is an INTER image, each pixel has subtracted from it the value of the pixel in the same spatial location in the previous image. The pixel differences are then vector-quantized and run-length encoded by means 340b. Further details of this vector-quantization and run-length encoding procedure are shown in Figure 3A and will be described below. The output of means 340b is a string of bytes with values corresponding to the values in the `index[]` array (divided by 2). This string of bytes is Huffman encoded by means 360 into variable-length codes. Further details of Huffman encoder 360 are shown in Figure 3B and will be described below. In the final encoding step, means 380 prepends the proper bitstream header.

Referring now to Figure 3A, there is shown a flow diagram illustrating the operation of means 340 of Figure 3. In

particular, Figure 3A shows the run-length encoding and vector quantization procedures of means 340b. The operation of means 340 is performed with a 2-state machine. The two states are denoted as ZERO and NONZERO. The ZERO state indicates that the system is in the middle of processing a run of 0 values. The NONZERO state indicates that non-zero values are being processed. The purpose of the two states is to allow for efficient encoding of consecutive zero differences.

In the first step of Figure 3A, means 342 initializes the state machine to the NONZERO state. Next, means 344 computes the next pair of pixel differences. In the preferred embodiment, the image is processed in normal raster-scan order, from top to bottom and left to right within each line. The "next pair" of pixels means the next two pixels on the current scan line being processed. As stated above, the differences are taken with the pixels immediately above these pixels (if this image is being encoded as an INTRA) or with the pixels in the same spatial location in the previous image (if this image is being encoded as an INTER image). Since these two values represent pixel differences, they will typically be small, or close to zero.

In the next step, means 346 operates to 2-D vector-quantize the two pixel difference values into a single number (index) between 0 and 127. The possible index values correspond to 128 points in 2-D space known as a "vector set". Geometrically, a vector set represents 128 points in the 2-D square bounded by the values -255 and 255 which have been chosen as reasonable approximations to every

point in the square. Thus, if the two pixel difference values are denoted by d_1 and d_2 , they can be represented as a point in the 2-D square with coordinates (d_1, d_2) . The vector quantization operation attempts to choose the closest (in Euclidean distance) of the 128 representative points to be used to encode the point (d_1, d_2) . Since the vector set is relatively small, this choosing operation can be done quickly using a lookup table. According to this procedure, the values d_1 and d_2 are first limited to the range -127 to $+127$. Then, the quantity 128 is added to produce values in the range 0 to 255. Next, a value p is calculated according to equation (1) below:

$$p = (d_1 \gg 2) \oplus (d_2 \gg 2 \ll 6) \quad (1)$$

The value of p is in the range 0 to 4095. The value at position ' p ' in a 4096-entry lookup table is then used to get the index corresponding to the closest representative point in the vector set corresponding to (d_1, d_2) . Although a slight inaccuracy in the computation is introduced by not using the lower 2 bits of d_1 and d_2 , without this step the lookup table would be 64K instead of 4K. A separate lookup table is required for each of the eight vector sets for a total size of 32K bytes. During encoding, the degree of quantization used (e.g., the VectorSet value chosen) is varied by known feedback processes which monitor the size of encoded images in the bitstream.

The remainder of Figure 3A maintains the value of a variable 'run' which indicates how many consecutive index values

of 0 have been produced. When a run of 0 values is ended, means 350 outputs the value 128+run. For each non-zero index, means 354 outputs the index value itself. Means 358 functions to repeat the process from (starting from means 344) until all pixels have been processed.

The encoding procedure shown in Figures 3,3A for a still (INTRA) image can be described by the c-language pseudo code in Table III below:

Define

```
Width = ImageWidth, divided by 2 depending on the
      value of Flags
Height = ImageHeight, divided by 2 depending on the
      value of Flags
```

Then

```
unsigned char *curr, *prev, grey[XMAX];
unsigned char *lookup

for (x=0; x<Width; x++) // make a line of 128's
  grey[x] = 128;

state = NONZERO;

for (y=0; y<Height; y++) // for each line of image

  curr = &bitmap[y][0];
  if (y > 0)
    prev = &bitmap[y-1][0];
  else
    prev = &grey[0];

  for (x=0; x<Width; x+=2)

    d1 = clamp(*curr++ - *prev++ + 128);
    d2 = clamp(*curr++ - *prev++ + 128);
    index = lookup[ (d1>> 2)    (d2>> 2 << 6) ];

    if (state == ZERO)

      if (index == 0)
        run++;
      else
```

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```

        huffenc(run + 128); huffenc(index);
        state = NONZERO;

    else if (state == NONZERO)

        if (index == 0)
            run = 1; state = ZERO;
        else
            huffenc(index);

```

where

'lookup' is a pointer to the 4K difference-pair-to-vector-index lookup table for the current vector set;

huffenc(x) is a function to output the appropriate Huffman codeword such that $\text{index}[\text{huffdec}(\text{huffenc}(x))] = x$.

TABLE III

The encoding procedure for an inter-frame image is similar to that described in Table III, and is obtained by deleting the first 2 lines of code, and changing the lines

```

    if (y > 0)
        prev = &bitmap[y-1][0];
    else
        prev = &grey[0];

```

to

```

    prev = &prev_bitmap[y][0];

```

Referring now to Figure 3B, there is shown a flow diagram illustrating the Huffman encoding of the byte values output by means 340b. The Huffman encoding step replaces the fixed 8-bit codes with a statistically-optimized set of variable-length codes. Before the Huffman encoding begins, two tables (table1 and table2) are precalculated to specify, for each 8-bit value to be Huffman encoded,

the number of bits in the Huffman code and the actual bits themselves. The bits are top-justified in a 16-bit value. The Huffman encoding operation is assisted by a 16-bit register called 'bitbuf' in which bits are collected. Another register, 'rbits', is used to indicate how many unused bits there are remaining in 'bitbuf'. Means 361 initially sets rbits to 16, since 'bitbuf' is initially empty.

Means 362 reads the next byte of data and looks up 'numbits' and 'bits' in the two tables. Decision block 363 determines whether there is room enough in 'bitbuf' to hold the entire Huffman code word, i.e., is $\text{numbits} \leq \text{rbits}$? If so, then 'bits' is ORed into 'bitbuf' by means 364, and 'rbits' is reduced by the value of 'numbits' by means 365. If it is determined by decision block 363 that the bits do not fit in 'bitbuf', then the encoder puts as many bits as will fit into 'bitbuf', outputs 'bitbuf', puts the remaining bits into bitbuf, and sets $\text{rbits} = 16 - \text{diff}$. More particularly, means 366 determines a value diff by subtracting rbits from numbits. Means 367 puts as many bits as will fit into bitbuf by ORing $(\text{bitbuf} \gg \text{rbits})$ with $(\text{bits} \ll \text{diff})$. Means 368 then outputs bitbuf and means 369 sets bitbuf to bits and rbits to 16 minus diff.

Decision block 370 determines whether the processing of all bytes is completed. If it is determined that all bytes have not been processed, the above process (starting with means 362) is repeated.

SYSTEM DETAILS

Two overall system block diagrams are shown in Figures 4A, 4B. Figure 4A shows a block diagram for recording and Figure 4B shows a block diagram for playback; however, the same system can be used (even simultaneously) for either recording (encoding) or playback (decoding).

Referring now to Figure 4A, the analog video is first digitized by video digitizer 410, and the digital images are stored in memory 420 in "YUV-9" format. This format consists of three planes of 8-bit pixels: one Y plane, one U plane, and one V plane. The U and V planes are stored at 1/4 the resolution in each dimension compared to the Y plane. Means 430 includes a set of control and synchronization routines which examine the images as they are digitized and invoke encoder 440 as appropriate in order to compress successive frames of the video. The bitstreams are then output to memory, from which they can be stored to hard disk or sent over a network.

Referring now to Figure 4B, a playback system according to the present invention is shown. The playback diagram of Figure 4B is the inverse of the record diagram shown in 4A. Thus, means 470 accepts as input compressed data and invokes decoder 480 as appropriate to decompress successive frames of the video. The decompressed video is stored in memory 460 in YUV-9 format. Display hardware 450 produces analog video from the YUV-9 data.

In the preferred embodiment, digitizer 410 can be programmed to digitize horizontally or vertically at any resolution. In effect, this means that the digitizer can be used to do part of the compression process. By programming the digitizer to a lower resolution, there will be less data for the encoder to compress and the final data size will be smaller. In addition, digitizer 410 may dynamically alter the digitizer resolution (either horizontally or vertically) when the video becomes "hard" to compress. A method and apparatus for dynamically altering resolution based on image complexity is implemented in U.S. Patent Application entitled, "Method and Apparatus For Encoding Selected Images At Lower Resolution" by A. Alattar, S. Golin and M. Keith, filed March 25, 1992, the serial number of which is not yet known, which application is assigned to the assignee of the present application and the contents of which are hereby incorporated herein by reference.

In the real time video system described above, the encoder takes incoming digitized images, compresses them, and outputs the compressed bitstream to a buffer in memory for extraction by the application. The simplistic view of the system assumes that everything works "ideally", so that a new compressed frame is generated exactly F times per second, where F is the desired frame rate requested by the user. However, there are at least two conditions which typically occur to make the operation of the system less than ideal:

- (1) The analog video source may disappear for a period, thus precluding new digitized images from being obtained by the digitizer; and
- (2) The application may not extract compressed frames from the buffer fast enough, which means that the encoding system gets "stalled" by the inability to output more compressed frames (caused by the output buffer being full).

In either case, if the encoder simply fails to output frames, this will result in a loss of time synchronization. For example, if the system is encoding at 30 frames per second, the playback system would expect to get 900 frames in 30 seconds. If, due to conditions (1) or (2), less than 900 frames are generated (for example, 840), then upon playback the playback system will play these 840 frames at 30 frames per second, and the playback of these frames will occupy only 28 seconds. This is not acceptable, since the video information upon playback will not occupy the same amount of real time that it did during recording. This will be evident to the viewer by, for example, loss of audio/video synchronization.

A solution to this problem is presented by what will be termed "sync frames". During encoding, means 430 keeps track of real time using a clock signal. It attempts to generate F compressed data frames per second, as requested by the user, and it monitors how well it is doing. If at any point it determines that it is behind (i.e., fewer frames have been generated so far than there should be), it inserts a

"sync frame" into the compressed buffer. A "sync frame" is a compressed data frame that appears in the bitstream just like a normal compressed frame (and so travels through the record and playback systems without any special handling) but which can be detected by the playback process as special.

The sync frame consists of the bitstream header (described above) with the DataSize field set to 128 and the other fields set to the appropriate values. A sync frame in effect counts the passage of time without causing a new image to appear on the screen. When the decoder encounters a sync frame, it simply copies the previous image to the current image bitmap. This results in no change to the display but the proper passage of time, so that accurate time synchronization results. Thus, if a system bottleneck occurs so that only 840 "real" compressed frames are created during a 30-second period, then means 430 will insert 60 sync frames. Thus, over the 30-second period there will be exactly 900 frames, as desired, but 60 of them will be sync frames. On playback, there will be some visual anomalies when the sync frames are processed, but exact time synchronization will be maintained.

The present invention may be implemented in real time (both compression and decompression) using an Intel model i750PB processor. Other processors, including Intel 386/486 processors, may be used to scalably decode video data which has been encoded accorded to the present invention.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes of the invention. Accordingly, reference should be made to the appended claims, rather than the foregoing specification, as indicating the scope of the invention.

APPENDIX

Vector set 0

128	128	132	132	124	124	127	133
129	123	133	127	123	129	140	140
116	116	131	141	125	115	141	131
115	125	119	137	137	119	137	119
119	137	140	149	116	107	149	140
107	116	124	144	132	112	144	124
112	132	150	150	106	106	130	152
126	104	152	130	104	126	151	162
105	94	162	151	94	105	162	162
94	94	139	163	117	93	163	139
93	117	113	149	143	107	149	113
107	143	120	157	136	99	157	120
99	136	127	167	129	89	167	127
89	129	164	177	92	79	177	164
79	92	150	177	106	79	177	150
79	106	178	178	78	78	101	155
155	101	155	101	101	155	137	180
119	76	180	137	76	119	106	163
150	93	163	106	93	150	115	172
141	84	172	115	84	141	180	195
76	61	195	180	61	76	164	195
92	61	195	164	61	92	196	196
60	60	150	198	106	58	198	150
58	106	124	186	132	70	186	124
70	132	91	171	165	85	171	91
85	165	99	180	157	76	180	99
76	157	134	202	122	54	202	134
54	122	182	215	74	41	215	182
41	74	200	215	56	41	215	200
41	56	164	216	92	40	216	164
40	92	108	193	148	63	193	108
63	148	217	217	39	39	128	128

Vector set 1

128	128	133	133	123	123	126	135
130	121	135	126	121	130	143	143
113	113	132	143	124	113	143	132
113	124	117	139	139	117	139	117
117	139	142	154	114	102	154	142
102	114	123	147	133	109	147	123
109	133	155	155	101	101	130	157
126	99	157	130	99	126	155	168
101	88	168	155	88	101	169	169
87	87	141	170	115	86	170	141
86	115	110	153	146	103	153	110
103	146	118	162	138	94	162	118
94	138	127	175	129	81	175	127

81	129	171	186	85	70	186	171
70	85	154	187	102	69	187	154
69	102	187	187	69	69	96	160
160	96	160	96	96	160	139	190
117	66	190	139	66	117	102	170
154	86	170	102	86	154	112	181
144	75	181	112	75	144	190	207
66	49	207	190	49	66	171	208
85	48	208	171	48	85	209	209
47	47	154	211	102	45	211	154
45	102	123	197	133	59	197	123
59	133	84	180	172	76	180	84
76	172	94	190	162	66	190	94
66	162	135	216	121	40	216	135
40	121	192	232	64	24	232	192
24	64	213	232	43	24	232	213
24	43	171	233	85	23	233	171
23	85	104	205	152	51	205	104
51	152	234	234	22	22	128	128

Vector set 2

128	128	134	134	122	122	126	136
130	120	136	126	120	130	146	146
110	110	133	146	123	110	146	133
110	123	115	141	141	115	141	115
115	141	145	158	111	98	158	145
98	111	121	151	135	105	151	121
105	135	160	160	96	96	131	162
125	94	162	131	94	125	160	176
96	80	176	160	80	96	177	177
79	79	143	178	113	78	178	143
78	113	107	158	149	98	158	107
98	149	116	169	140	87	169	116
87	140	127	184	129	72	184	127
72	129	180	197	76	59	197	180
59	76	159	198	97	58	198	159
58	97	198	198	58	58	89	167
167	89	167	89	89	167	141	202
115	54	202	141	54	115	97	178
159	78	178	97	78	159	109	191
147	65	191	109	65	147	202	223
54	33	223	202	33	54	179	223
77	33	223	179	33	77	225	225
31	31	159	227	97	29	227	159
29	97	122	211	134	45	211	122
45	134	76	190	180	66	190	76
66	180	87	202	169	54	202	87
54	169	136	233	120	23	233	136
23	120	204	251	52	5	251	204
5	52	230	251	26	5	251	230
5	26	180	253	76	3	253	180
3	76	99	220	157	36	220	99
36	157	254	254	2	2	128	128

Vector set 3

128	128	135	135	121	121	126	137
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130	119	137	126	119	130	149	149
107	107	134	150	122	106	150	134
106	122	112	144	144	112	144	112
112	144	148	164	108	92	164	148
92	108	120	155	136	101	155	120
101	136	166	166	90	90	131	169
125	87	169	131	87	125	166	185
90	71	185	166	71	90	186	186
70	70	146	188	110	68	188	146
68	110	103	163	153	93	163	103
93	153	114	176	142	80	176	114
80	142	127	195	129	61	195	127
61	129	190	210	66	46	210	190
46	66	165	212	91	44	212	165
44	91	212	212	44	44	82	174
174	82	174	82	82	174	143	216
113	40	216	143	40	113	91	187
165	69	187	91	69	165	105	203
151	53	203	105	53	151	216	240
40	16	240	216	16	40	189	241
67	15	241	189	15	67	243	243
13	13	165	246	91	10	246	165
10	91	120	226	136	30	226	120
30	136	66	201	190	55	201	66
55	190	79	216	177	40	216	79
40	177	138	253	118	3	253	138
3	118	219	255	37	1	255	219
1	37	249	255	7	1	255	249
1	7	190	255	66	1	255	190
1	66	94	237	162	19	237	94
19	162	255	255	1	1	128	128

Vector set 4

128	128	136	136	120	120	126	138
130	118	138	126	118	130	152	152
104	104	134	154	122	102	154	134
102	122	110	146	146	110	146	110
110	146	152	170	104	86	170	152
86	104	120	160	136	96	160	120
96	136	172	172	84	84	132	176
124	80	176	132	80	124	174	196
82	60	196	174	60	82	196	196
60	60	150	198	106	58	198	150
58	106	98	170	158	86	170	98
86	158	112	186	144	70	186	112
70	144	126	206	130	50	206	126
50	130	200	226	56	30	226	200
30	56	172	226	84	30	226	172
30	84	228	228	28	28	74	182
182	74	182	74	74	182	146	232
110	24	232	146	24	110	84	198
172	58	198	84	58	172	102	216
154	40	216	102	40	154	232	255
24	0	255	232	0	24	200	255
56	0	255	200	0	56	255	255
0	0	172	255	84	0	255	172
0	84	120	244	136	12	244	120

12	136	54	214	202	42	214	54
42	202	70	232	186	24	232	70
24	186	140	255	116	0	255	140
0	116	236	255	20	0	255	236
0	20	255	255	0	0	255	255
0	0	200	255	56	0	255	200
0	56	88	255	168	0	255	88
0	168	255	255	0	0	128	128

Vector set 5

128	128	138	138	118	118	124	142
132	114	142	124	114	132	158	158
98	98	136	158	120	98	158	136
98	120	106	150	150	106	150	106
106	150	156	180	100	76	180	156
76	100	118	166	138	90	166	118
90	138	182	182	74	74	132	186
124	70	186	132	70	124	182	208
74	48	208	182	48	74	210	210
46	46	154	212	102	44	212	154
44	102	92	178	164	78	178	92
78	164	108	196	148	60	196	108
60	148	126	222	130	34	222	126
34	130	214	244	42	12	244	214
12	42	180	246	76	10	246	180
10	76	246	246	10	10	64	192
192	64	192	64	64	192	150	252
106	4	252	150	4	106	76	212
180	44	212	76	44	180	96	234
160	22	234	96	22	160	252	255
4	0	255	252	0	4	214	255
42	0	255	214	0	42	255	255
0	0	180	255	76	0	255	180
0	76	118	255	138	0	255	118
0	138	40	232	216	24	232	40
24	216	60	252	196	4	252	60
4	196	142	255	114	0	255	142
0	114	255	255	0	0	255	255
0	0	255	255	0	0	255	255
0	0	214	255	42	0	255	214
0	42	80	255	176	0	255	80
0	176	255	255	0	0	128	128

Vector set 6

128	128	140	140	116	116	124	144
132	112	144	124	112	132	164	164
92	92	138	164	118	92	164	138
92	118	102	154	154	102	154	102
102	154	162	188	94	68	188	162
68	94	114	174	142	82	174	114
82	142	192	192	64	64	134	196
122	60	196	134	60	122	192	224
64	32	224	192	32	64	226	226
30	30	158	228	98	28	228	158
28	98	86	188	170	68	188	86
68	170	104	210	152	46	210	104

46	152	126	240	130	16	240	126
16	130	232	255	24	0	255	232
0	24	190	255	66	0	255	190
0	66	255	255	0	0	50	206
206	50	206	50	50	206	154	255
102	0	255	154	0	102	66	228
190	28	228	66	28	190	90	254
166	2	254	90	2	166	255	255
0	0	255	255	0	0	230	255
26	0	255	230	0	26	255	255
0	0	190	255	66	0	255	190
0	66	116	255	140	0	255	116
0	140	24	252	232	4	252	24
4	232	46	255	210	0	255	46
0	210	144	255	112	0	255	144
0	112	255	255	0	0	255	255
0	0	255	255	0	0	255	255
0	0	232	255	24	0	255	232
0	24	70	255	186	0	255	70
0	186	255	255	0	0	128	128

Vector set 7

128	128	142	142	114	114	128	146
132	110	146	124	110	132	110	170
86	86	140	172	116	84	172	140
84	116	96	160	160	96	160	96
96	160	168	200	88	56	200	168
56	88	112	182	144	74	182	112
74	144	204	204	52	52	134	210
122	46	210	134	46	122	204	242
52	14	242	204	14	52	244	244
12	12	164	248	92	8	248	164
8	92	78	198	178	58	198	78
58	178	100	224	156	32	224	100
32	156	126	255	130	0	255	126
0	130	252	255	4	0	255	252
0	4	202	255	54	0	255	202
0	54	255	255	0	0	36	220
220	36	220	36	36	220	158	255
98	0	255	158	0	98	54	246
202	10	246	54	10	202	82	255
174	0	255	82	0	174	255	255
0	0	255	255	0	0	250	255
6	0	255	250	0	6	255	255
0	0	202	255	54	0	255	202
0	54	112	255	144	0	255	112
0	144	4	255	252	0	255	4
0	252	30	255	226	0	255	30
0	226	148	255	108	0	255	148
0	108	255	255	0	0	255	255
0	0	255	255	0	0	255	255
0	0	252	255	4	0	255	252
0	4	60	255	196	0	255	60
0	196	255	255	0	0	128	128

What is claimed is:

1. A method for decoding in real time a bitstream representative of at least one digital video image comprising the steps of:

- (A) providing a code-book index from said bitstream;
- (B) applying said code-book index to an index table to determine an index value;
- (C) comparing said index value to a first predetermined threshold;
- (D) if said index value is greater than said predetermined threshold then

determining at least one current pixel by copying a corresponding previous pixel into the location of said at least one current pixel

otherwise

applying said index value to a vector table to determine at least one vector value, and determining said at least one current pixel from said at least one vector value and said corresponding previous pixel.

2. The method of Claim 1, wherein said corresponding previous pixel is positioned directly above said at least one current pixel.

3. The method of Claim 1, wherein said corresponding previous pixel is in a frame preceding said at least one current pixel.

4. The method of claim 1, wherein step (D) comprises the following steps:

- (D) if said index value is greater than said predetermined threshold then
 - (i) calculating a counter from the magnitude said index value exceeds said predetermined threshold;
 - (ii) determining two current pixels by copying two corresponding previous pixels into the respective locations of said two current pixels; and
 - (iii) repeating step (ii) counter minus one times;otherwise
 - (iv) applying said index value to a vector table to determine first and second vector values; and
 - (v) determining said two current pixels from said first vector value, said second vector value and said two corresponding previous pixels.

5. The method of claim 1, wherein said code-book index is provided in step (A) from Huffman decoding of said bitstream.

6. The method of claim 1, further comprising the steps of:
 - (E) repeating steps (A)-(D) until each current pixel in said at least one digital video image has been determined;
 - (F) determining whether said at least one digital video image was compressed at a lower level of resolution; and
 - (G) if said at least one digital video image was compressed at a lower level of resolution then scaling the result of step (E) up to full resolution.
7. The method of claim 4, wherein step (D)(iv) comprises the steps of:
 - (a) selecting a vector table from a plurality of vector tables; and
 - (b) applying said index value to said selected vector table to determine first and second vector values.
8. A method for encoding at least one digital video image in real time comprising the steps of:
 - (A) selecting at least one pixel for encoding;
 - (B) determining at least one difference value between said at least one selected pixel and at least one corresponding previous pixel;

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- (C) calculating an index value corresponding to the location in a first table of said at least one difference value;
 - (D) if said index value is equal to a first predetermined value then
 - (i) incrementing a run-length counter by a second predetermined value;
 - (ii) repeating steps (A) - (D)(i) until said index value is not equal to said first predetermined value;
 - (iii) incrementing said run-length counter by a third predetermined value;
 - (iv) encoding said run-length counter; and
 - (E) if said index value is not equal to said first predetermined value then encoding said index value.
9. The method of claim 8, wherein huffman encoding is used to encode said run-length counter in step (D)(iv) and said index value in step (F).
10. The method of claim 8, wherein said first predetermined value is zero.
11. The method of claim 8 wherein step (A) comprises selecting first and second pixels for encoding, step (B) comprises the steps of:

- (i) determining a first difference value between said first selected pixel and a first corresponding previous pixel;
- (ii) determining a second difference value between said second selected pixel and a second corresponding previous pixel; and

step (C) comprises quantizing said first and second difference values into an index value corresponding to the location of said first difference value in a first table, wherein said first and second difference values are adjacent to each other in said first table.

12. An apparatus for decoding in real time a bitstream representative of at least one digital video image comprising:

- (A) means for providing a code-book index from said bitstream;
- (B) means for applying said code-book index to an index table to determine an index value;
- (C) means for comparing said index value to a first predetermined threshold;
- (D) means for determining at least one current pixel by copying a corresponding previous pixel into the location of said at least one current pixel if said index value is greater than said predetermined threshold;
- (E) means for applying said index value to a first vector table to determine at least one vector value

if said index value is not greater than said predetermined threshold; and

(F) means for determining said at least one current pixel from said at least one vector value and said corresponding previous pixel.

13. The apparatus of Claim 12, wherein said corresponding previous pixel is positioned directly above said at least one current pixel.

14. The apparatus of Claim 12, wherein said corresponding previous pixel is in a frame preceding said at least one current pixel.

15. The apparatus of claim 12, wherein said means for determining at least one current pixel by copying a corresponding previous pixel comprises:

- (i) means for calculating a counter from the magnitude said index value exceeds said predetermined threshold;
- (ii) means for determining two current pixels by copying two corresponding previous pixels into the respective locations of said two current pixels;

said means for applying said index value to a first vector table to determine at least one vector value comprises means for applying said index value to a vector table to determine first and second vector values; and

said means for determining said at least one current pixel from said at least one vector value and said corresponding previous pixel comprises means for determining said two current pixels from said first vector value, said second vector value and said two corresponding previous pixels.

16. The apparatus of claim 12, further comprising:

(G) means for determining whether said at least one digital video image was compressed at a lower level of resolution; and

(H) means for scaling a lower resolution image up to full resolution.

17. The apparatus of claim 15, further comprising:

(G) means for selecting a vector table from a plurality of vector tables; and

(H) means for applying said index value to said selected vector table to determine first and second vector values.

18. An apparatus for encoding at least one digital video image in real time comprising:

(A) means for selecting at least one pixel for encoding;

(B) means for determining at least one difference value between said at least one selected pixel and at least one corresponding previous pixel;

- (C) means for calculating an index value corresponding to the location in a first table of said at least one difference value;
- (D) means for comparing said index value to a first predetermined value;
- (E) means for incrementing a run-length counter by a second predetermined value if said index value is equal to said first predetermined value;
- (F) means for encoding said run-length counter; and
- (G) means for encoding said index value if said index value is not equal to said first predetermined value.

19. The apparatus of claim 18, further comprising means for huffman encoding said run-length counter and said index value.

20. The apparatus of claim 18, wherein said first predetermined value is zero.

21. The apparatus of claim 18 wherein said means for selecting at least one pixel for encoding comprises means for selecting first and second pixels for encoding, said means for means for determining at least one difference value comprises:

- (i) means for determining a first difference value between said first selected pixel and a first corresponding previous pixel;

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(ii) means for determining a second difference value between said second selected pixel and a second corresponding previous pixel; and

said means for calculating an index value comprises means for quantizing said first and second difference values into an index value corresponding to the location of said first difference value in a first table, wherein said first and second difference values are adjacent to each other in said first table.

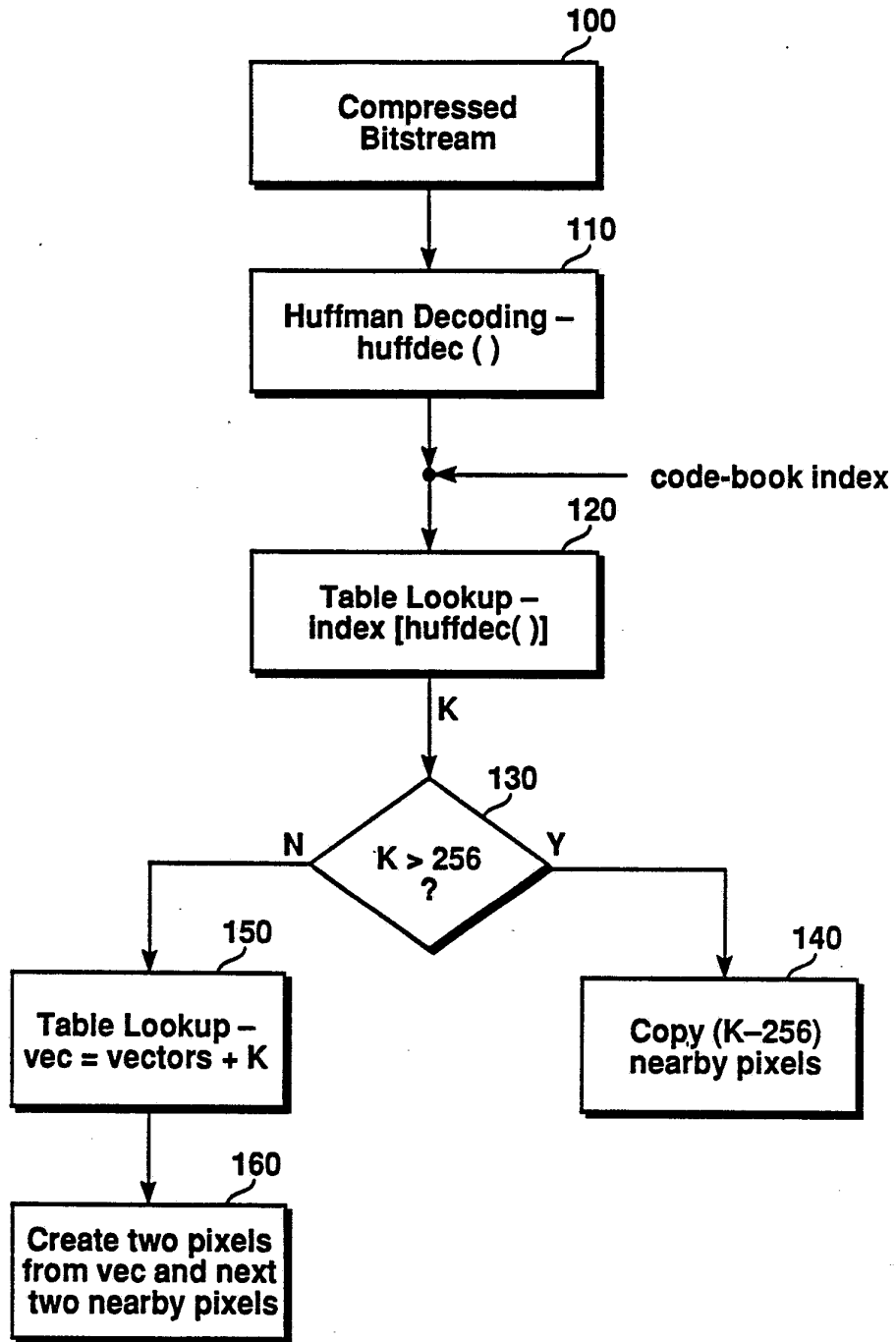


FIGURE 1

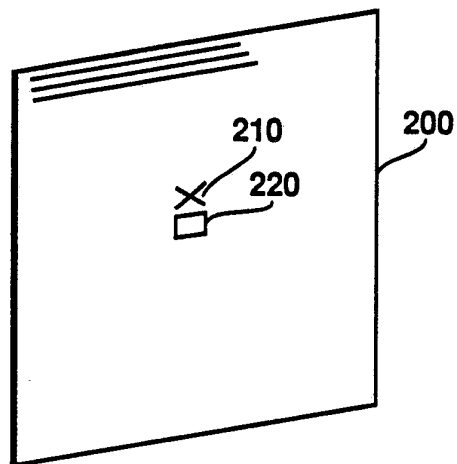


FIGURE 2A

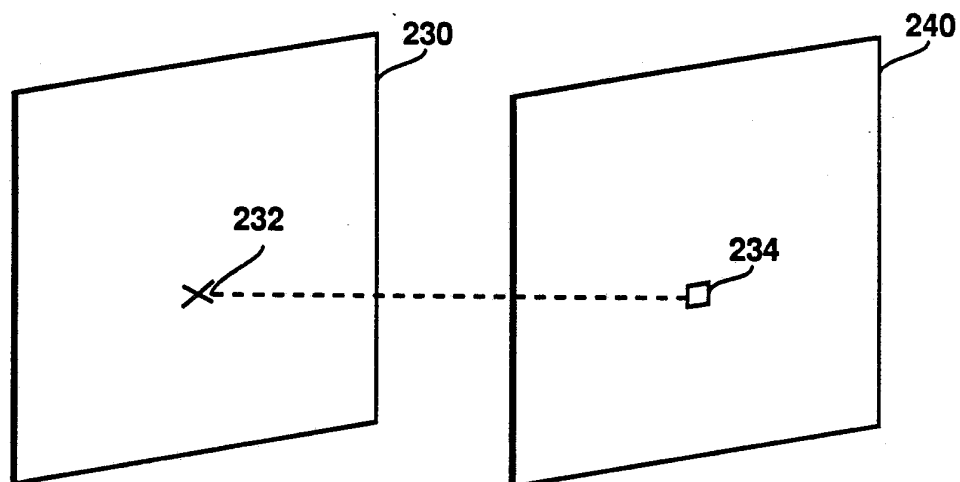


FIGURE 2B

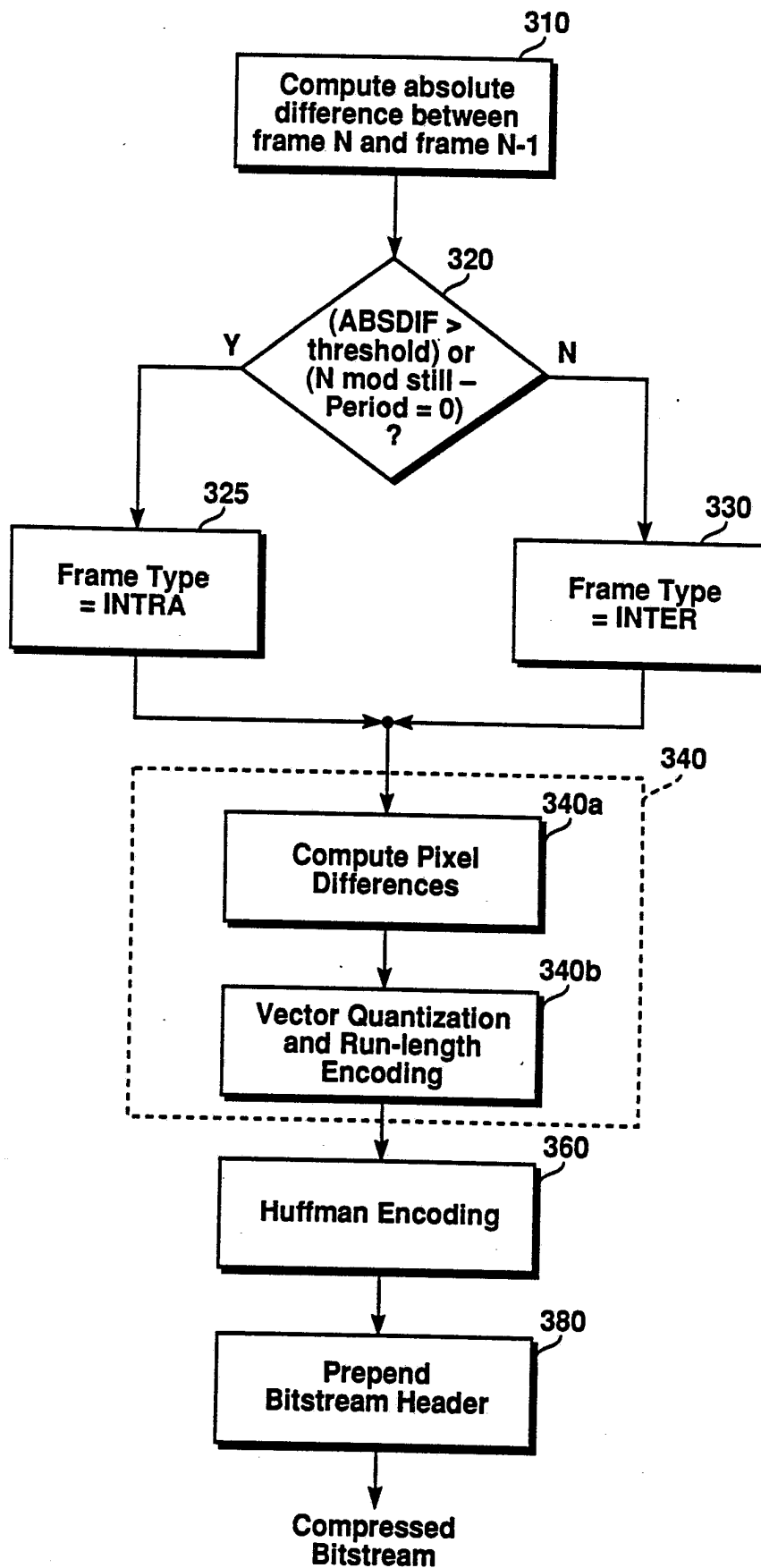


FIGURE 3

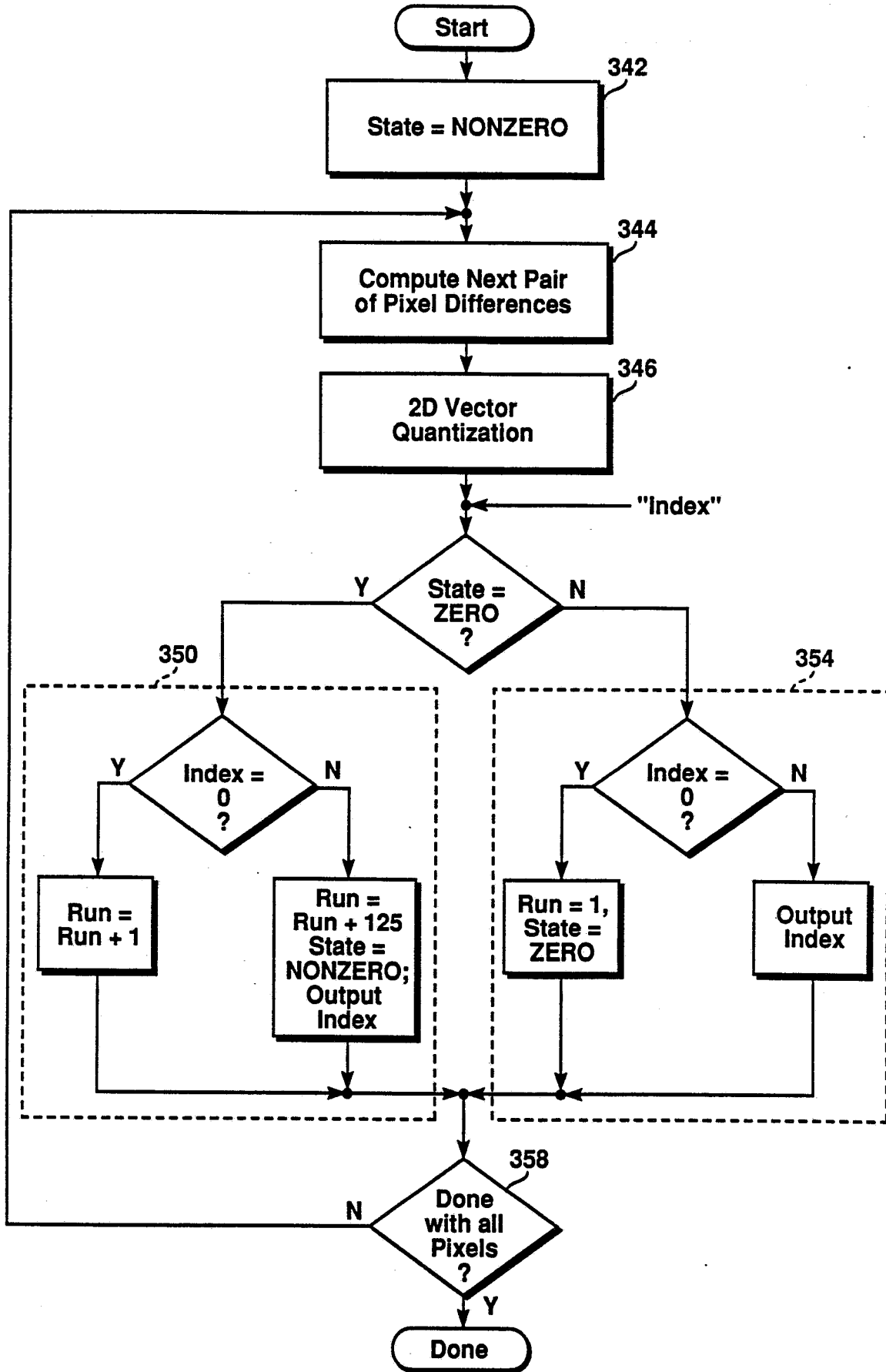


FIGURE 3A

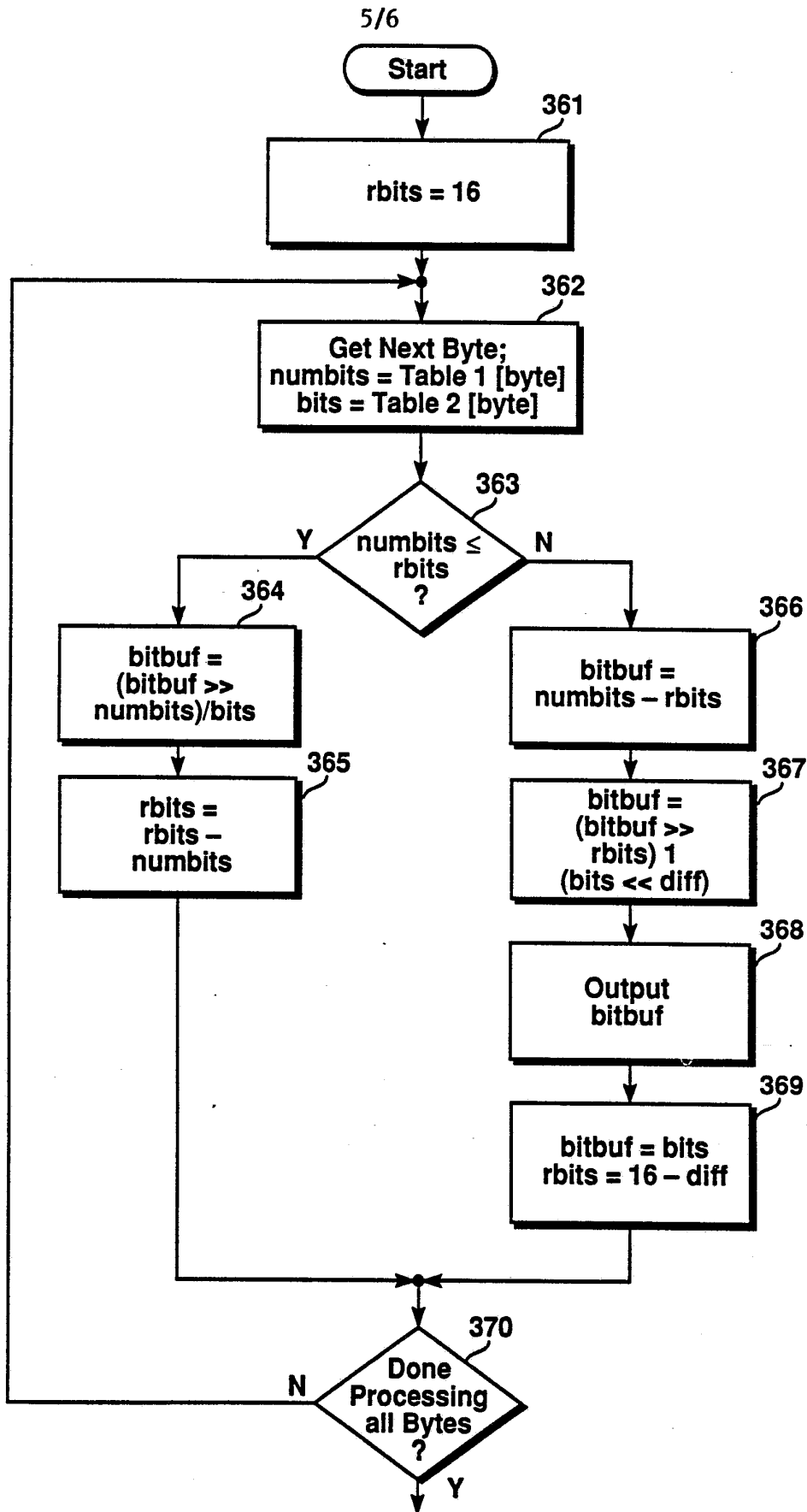


FIGURE 3B

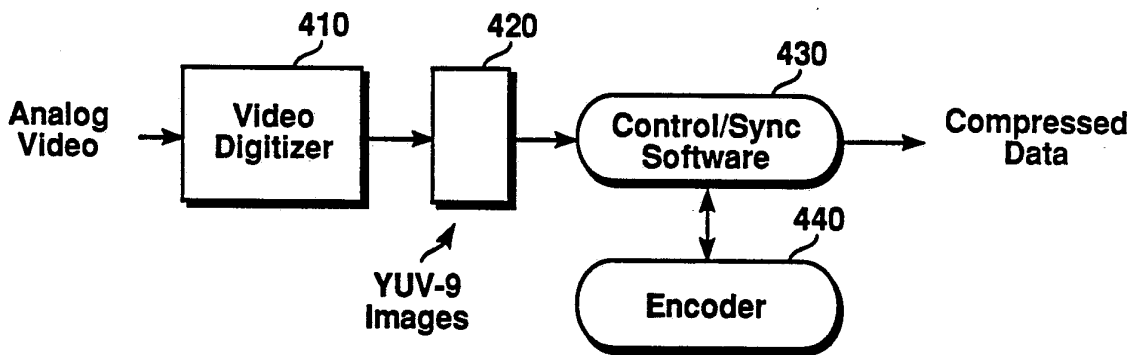


FIGURE 4A

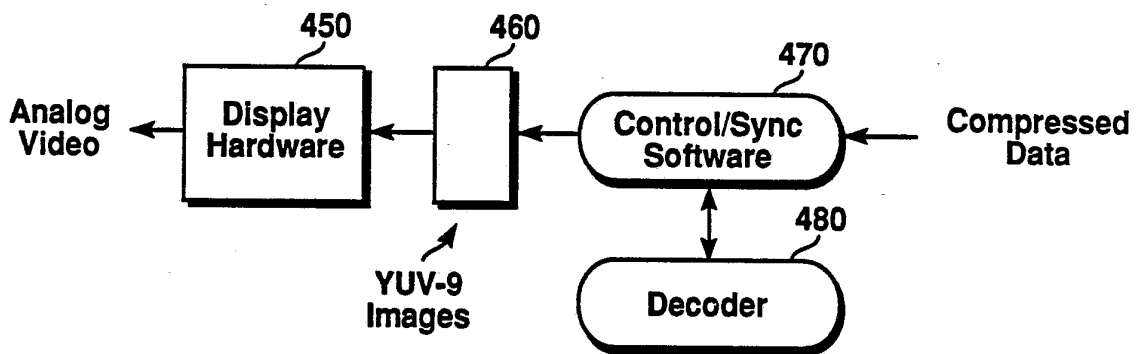


FIGURE 4B

INTERNATIONAL SEARCH REPORT

PCT/US 93/02583

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 H04N7/13; H04N7/137		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
Int.Cl. 5	H04N	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category ^o	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US,A,4 813 056 (FEDELE) 14 March 1989	1-3, 5, 8-10, 12-14, 18-20
Y	see column 1, line 28 - column 11, line 2 see column 15, line 61 - column 17, line 43 ---	4, 6-7, 11, 15-17, 21
Y	SIGNAL PROCESSING: IMAGE COMMUNICATION vol. 2, no. 1, May 1990, pages 81 - 94 THYAGARAJAN ET AL. 'Encoding of videoconferencing signals using VDPCM' see paragraph 1 see paragraph 3 -paragraph 4 ---	4, 7, 11, 15, 17, 21
	-/--	
<p>^o Special categories of cited documents : ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"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</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
14 JULY 1993	09. 08. 93	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	POIRIER, J.	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		Relevant to Claim No.
Category ^o	Citation of Document, with indication, where appropriate, of the relevant passages	
Y	<p>IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE December 1986, HOUSTON pages 1158 - 1164 RUTLEDGE 'Vector DPCM : Vector Predictive Coding of Color Images' see the whole document</p> <p style="text-align: center;">---</p>	4, 11, 15, 21
Y	<p>US,A,4 684 923 (KOGA) 4 August 1987 see column 3, line 61 - column 5, line 18 see column 16, line 50 - column 18, line 16</p> <p style="text-align: center;">---</p>	6, 16
A	<p>COMMUNICATIONS OF THE ACM vol. 34, no. 4, April 1991, NEW YORK pages 64 - 78 HARNEY ET AL. 'The i750 Video Processor : A Total Multimedia Solution' see page 67, left column, line 47 - middle column, line 23 see page 75, left column, line 12 - page 76, right column, line 41</p> <p style="text-align: center;">---</p>	4, 11, 15, 21
A	<p>US,A,4 785 349 (KEITH ET AL.) 15 November 1988 see column 41, line 38 - column 42, line 3 see claim 10</p> <p style="text-align: center;">---</p>	4, 11, 15, 21
A	<p>IEEE TRANSACTIONS ON COMMUNICATIONS vol. 36, no. 8, August 1988, NEW YORK pages 957 - 971 NASRABADI ET AL. 'Image Coding Using Vector Quantization : A Review' see paragraph 3-B see paragraph 4</p> <p style="text-align: center;">-----</p>	1-21

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

US 9302583
SA 72263

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 14/07/93

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