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# United States Patent [19]

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Ginosar et al.

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- [54] **WIDE DYNAMIC RANGE CAMERA**
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- [73] Assignee: **i Sight, Inc.**, Orangeburg, N.Y.
- [21] Appl. No.: **799,666**
- [22] Filed: **Nov. 21, 1991**

### FOREIGN PATENT DOCUMENTS

- 3436057 5/1985 Fed. Rep. of Germany .
- 3641186 7/1987 Fed. Rep. of Germany .

### OTHER PUBLICATIONS

- Abstract of Japanese Patent Publication No. 59/122288.
- Abstract of Japanese Patent Publication 59/122182.
- Int. Classification (Section G 06 K, 9/56) 5th Ed., 1989.

*Primary Examiner*—John K. Peng  
*Attorney, Agent, or Firm*—William H. Dippert; Ronald E. Brown

### Related U.S. Application Data

- [63] Continuation of Ser. No. 338,547, Aug. 2, 1989, abandoned.

### Foreign Application Priority Data

- Feb. 8, 1988 [IL] Israel ..... 87306
- [51] Int. Cl.<sup>5</sup> ..... **H04N 5/30; H04N 5/14; H04N 5/238**
- [52] U.S. Cl. .... **358/209; 358/166; 358/228; 358/909**
- [58] Field of Search ..... 358/209, 909, 166, 228

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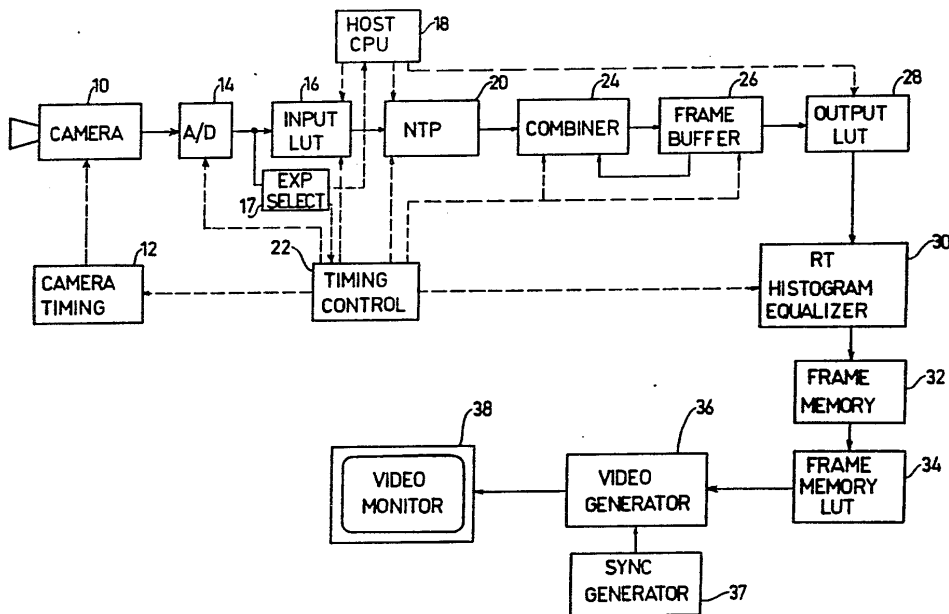
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- 4,450,482 5/1984 Ackermann ..... 358/160
- 4,584,606 4/1986 Nagasaki et al. .... 358/209
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### ABSTRACT

This invention is directed to a wide dynamic range video imaging apparatus. More specifically, the invention is directed to a video imaging apparatus comprising a) a sensor for providing a plurality of video images of a scene at different exposure levels and b) a processor for processing the plurality of video images to produce a combined video image including image information from the plurality of video images by applying neighborhood transforms to the plurality of video images, the processor comprising a selector for locally selecting the operating levels of the dynamic range of the combined video image within the dynamic range of the sensor, whereby the resulting video image includes image information from the plurality of video images with enhanced information content at local areas therein.

10 Claims, 6 Drawing Sheets



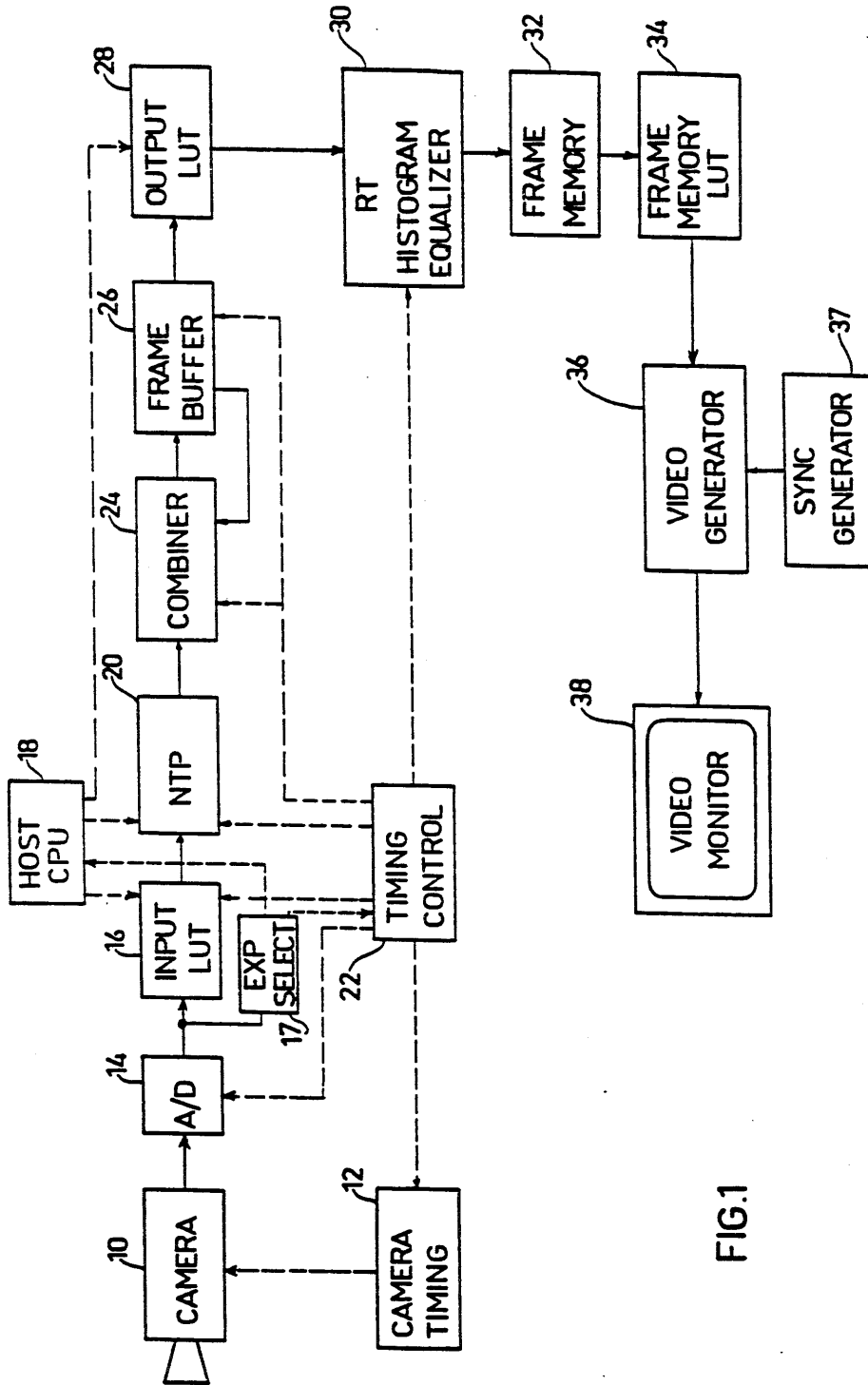
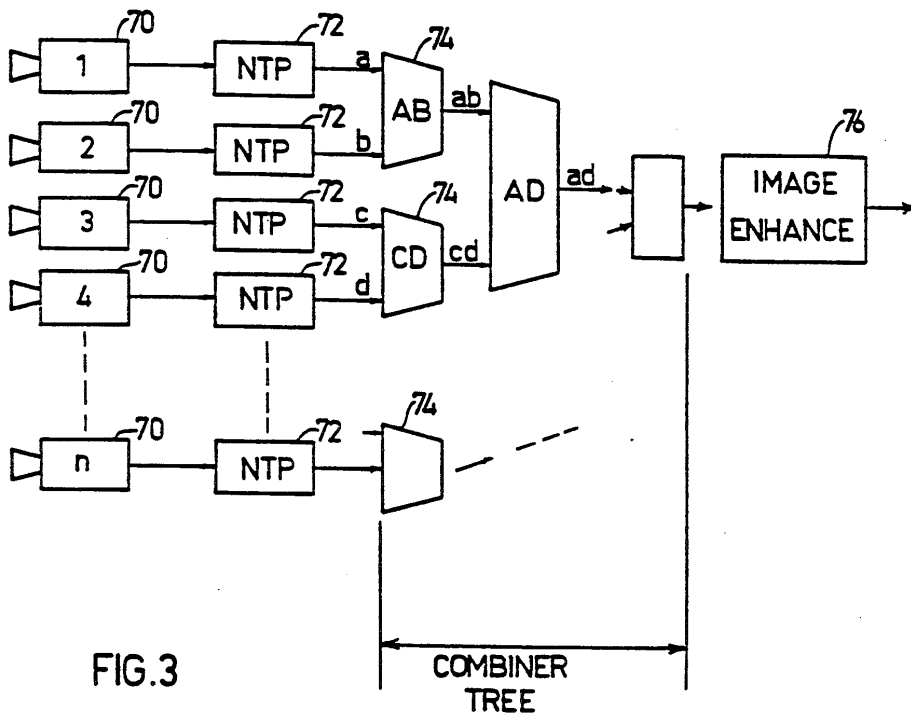
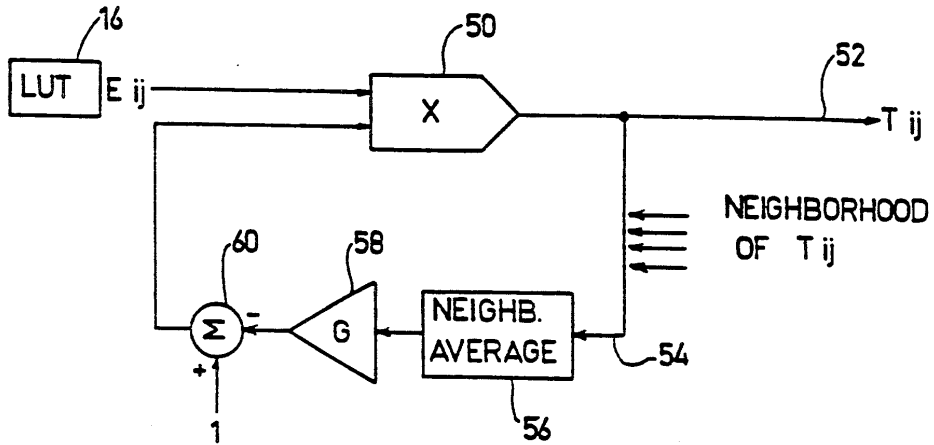


FIG.1

FIG. 2



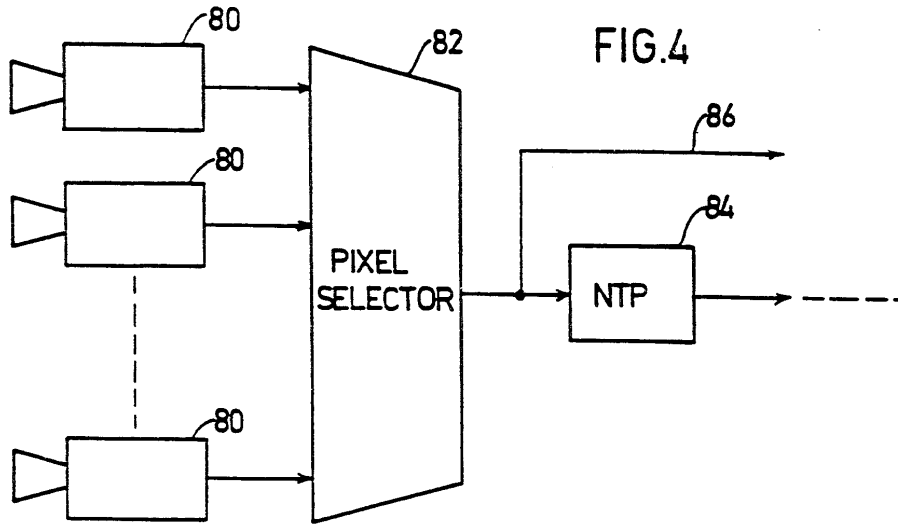
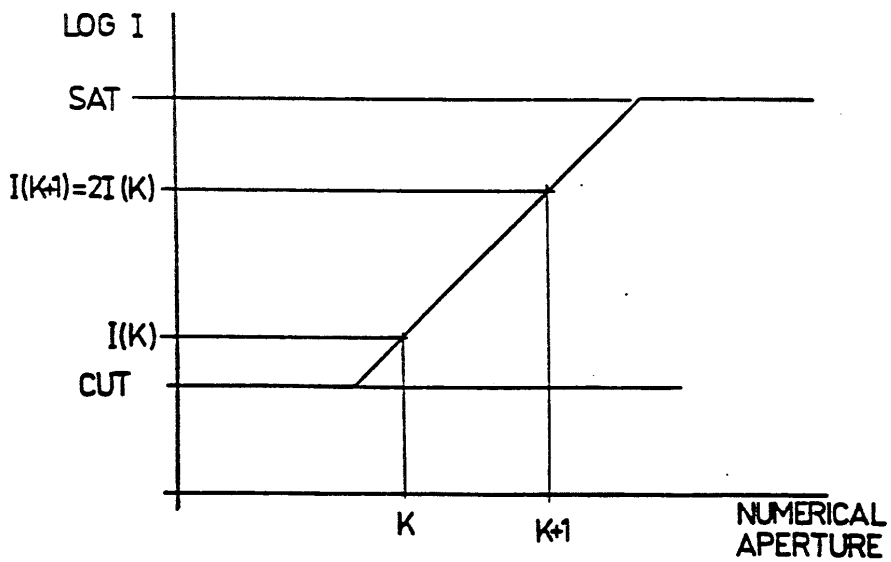


FIG. 5



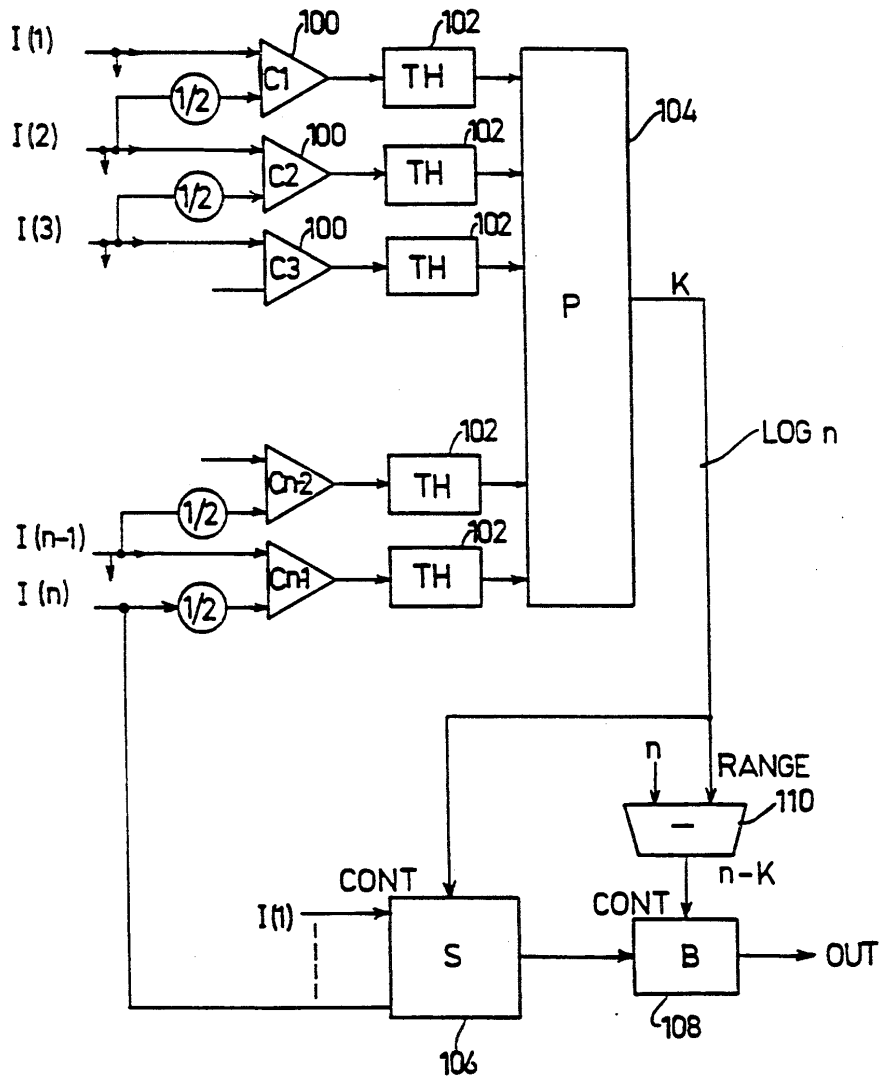


FIG. 6

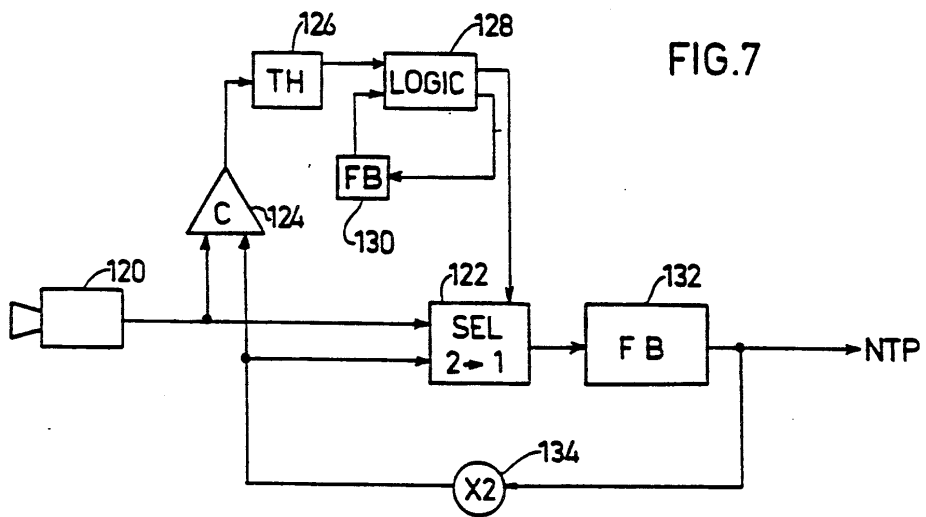
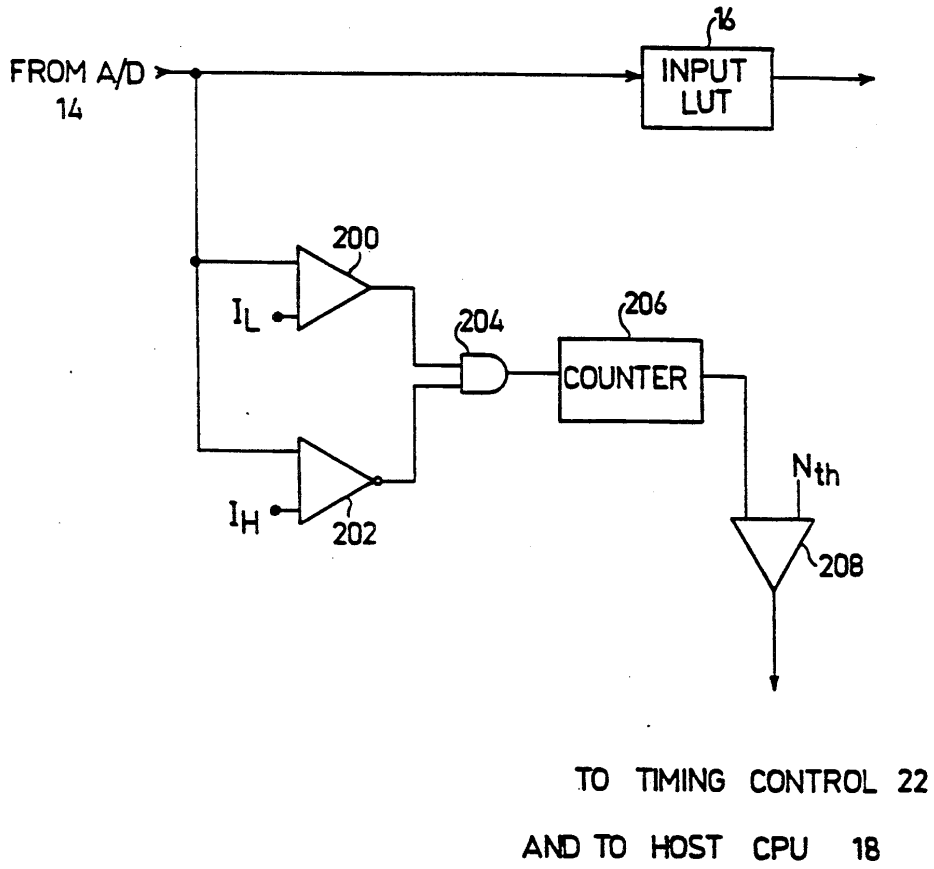


FIG. 8



## WIDE DYNAMIC RANGE CAMERA

This application is continuation of U.S. patent application Ser. No. 338,547, filed Aug. 2, 1989, now abandoned.

### FIELD OF THE INVENTION

The present invention relates to video imagery and more particularly to apparatus and techniques for providing enhanced video images.

### BACKGROUND OF THE INVENTION

Various types of video image enhancement apparatus and techniques have been proposed. Automatic Gain Control (AGC) techniques have been employed, inter alia, in video signals for reducing the dynamic range of the video signal by subtraction of its DC level. Such a technique is described in U.S. Pat. No. 4,719,350, wherein linear AGC is applied to the video image on a pixel by pixel basis. This technique is applicable only to a solid area which is delimited by a line parallel to the scan direction.

Generally speaking, AGC is employed in video processing only on a frame by frame basis.

### SUMMARY OF THE INVENTION

The present invention seeks to provide improved video image enhancement apparatus which overcomes limitations of the prior art apparatus and techniques discussed above.

There is thus provided in accordance with a preferred embodiment of the present invention, video imaging apparatus including apparatus for providing a plurality of video images of a scene at different exposure levels and apparatus for processing the plurality of video images to produce a combined video image including image information from the plurality of video images and including enhanced detail at local areas therein.

Further in accordance with a preferred embodiment of the invention, the apparatus for processing the plurality of video images comprises apparatus for locally enhancing the dynamic range of portions of the combined video image.

Additionally in accordance with a preferred embodiment of the invention, the apparatus for processing the plurality of video images comprises apparatus for preserving edge indicating information in the combined video image.

Further in accordance with an embodiment of the invention, the apparatus for processing the plurality of video images comprises apparatus for applying neighborhood transforms to the plurality of video images.

Additionally in accordance with a preferred embodiment of the present invention, there is provided video image enhancement apparatus comprising apparatus for providing a plurality of video images of a scene at different exposure levels and apparatus for processing the plurality of video images to produce a combined video image including image information from the plurality of video images and including enhanced detail at local areas therein.

Additionally, in accordance with a preferred embodiment of the invention, apparatus for processing may also include image enhancement apparatus such as histogram equalization apparatus.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

FIG. 1 is a block diagram illustration of a video imaging system constructed and operative in accordance with a preferred embodiment of the present invention;

FIG. 2 is a simplified block diagram of neighborhood transform apparatus which provides a non-linear neighborhood transform;

FIG. 3 is a block diagram illustration of an alternative video imaging system constructed and operative in accordance with an alternative preferred embodiment of the present invention;

FIG. 4 is a block diagram illustration of a further video imaging system constructed and operative in accordance with an alternative preferred embodiment of the present invention;

FIG. 5 is a graphical illustration of the operation of the video imaging system of FIG. 4;

FIG. 6 is a block diagram illustration of a pixel selector useful in the embodiment of FIG. 5;

FIG. 7 is a block diagram illustration of yet a further alternative embodiment of a video imaging system constructed and operative in accordance with a preferred embodiment of the present invention; and

FIG. 8 is a block diagram illustration of an exposure selector forming part of the circuitry of FIG. 1.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to FIG. 1, which illustrates one preferred embodiment of a video imaging system constructed and operative in accordance with a preferred embodiment of the present invention and which comprises a camera 10, such as a CCD, CID, photodiode array or any other visible or non-visible light sensor array which permits the exposure time to be varied by externally supplied control pulses or which permits any other form of external exposure control. One commercially available example of camera 10 is a model RVS-09 available from Xybion Electronic Systems Corp. of San Diego, Calif., U.S.A.

Camera timing circuitry 12 supplies timing pulses to camera 10. The timing circuitry 12 may comprise conventional clocks, counters and frequency dividers. The timing pulses supplied to camera 10 are operative to actuate the photoelectric accumulation of charge in the sensor arrays for varying periods of selectable duration and are also operative to govern the read-out of the signal currents produced by sensing through pre-amplifier circuits preferably incorporated within camera 10 to an A/D converter 14. A typical suitable A/D converter is a TRW TDC-1048 which operates at 10 MHz at 8 bit resolution. Control of the photoelectric accumulation of charge may be accomplished generally in two ways, by operating a shutter, such as an electronic shutter to control the light input or by controlling the integration time of the sensor array.

The digitized video data from A/D converter 14 is supplied in parallel to two subsystems, a Look Up Table (LUT) 16 and an exposure selector 17. The exposure selector is illustrated in FIG. 8 and comprises first and second comparators 200 and 202 arranged in parallel and outputting to an AND gate 204. Comparator 200 compares the signal from A/D converter 14 with a low threshold level I(L), such as a signal level of 20, in an



8-bit range of 0-255. Comparator 202 compares the signal from A/D converter 14 with a high threshold value I(H), such as 235. If the signal is above 20 and below 235, then the two comparators both generate logic "true" signals which are ANDed by AND gate 204.

The output of AND gate 204 is supplied to a counter 206, for incrementing thereof when two "true" signals are received at AND gate 204.

Counter 206 is reset to zero at the beginning of each frame. If the image of the current frame is mostly saturated, i.e. many pixels are white (having, for example, a digital value of 255 or close thereto), then at the end of the frame the counter will contain a very low number. Such will also be the case, if the image is mostly cut-off, i.e. many pixels are black, (i.e. having a digital value of 20 or less).

Conversely, for "normal" images, which possess a certain spread of values, a large number of the pixels will have values between 20 and 235. For frames of such images, the counter 206 will contain a large number at the end of each frame.

The output of counter 206 is supplied to a comparator 208. At the end of each frame, the output of counter 206 is compared by comparator 208 with a threshold value N(th). This threshold is selected to determine whether the image of the frame was a "normal" one, as opposed to an image that was mainly saturated or cut-off. If the value of the counter 206 output is higher than N(th), then the output of the comparator 208 is a logic "true". That output is supplied to both the timing control circuitry 22 and the host CPU 18 (FIG. 1).

The measurement and determination of whether a certain frame at a given exposure level should or should not be combined with a plurality of frames at different exposure levels may be carried out in at least two ways.

According to one embodiment of the invention, the measurement can be done on a relatively infrequent basis, as determined by the host CPU 18. In such a case, a complete series of exposures, covering the full range of exposures of which the system is capable, is carried out. At the end of each exposure, the output of comparator 208 is received by the host CPU 18.

The host CPU 18 controls the parameters I(L), I(H) and N(th), and can modify them at will. The information gathered assists the host CPU 18 to determine which exposures will be taken or used until the next measurement.

According to an alternative embodiment of the present invention, the measurement can be carried out on a continuous basis. The series of exposures begins from an intermediate exposure setting, such as that determined by a conventional exposure meter, and proceeds towards the two extremes.

For example, it may be assumed that there exist 15 possible exposure levels, where number 1 is the shortest (having the least sensitivity and number 15 is the longest (having the greatest sensitivity). The system typically proceeds by starting a new sequence with exposure number 7, and then proceeds with numbers 6, 5, . . . 1. When a cut-off frame is encountered, for which comparator 208 produces a logic "false" output, the progression of the sequence in that direction is terminated and the sequence proceeds with exposure numbers 8, 9, . . . 15. When a saturated frame is encountered, the sequence is complete. In such a case, the system may receive exposure numbers 3 through 13, of which expo-

sure numbers 3 and 13 are cut-off and saturated, respectively, and exposure numbers 4-12 are "normal".

It is appreciated that not all of the exposures may be necessary. For example, two consecutive images taken at exposure levels separated by one may be very similar and the amount of information provided by one as compared with the other may be marginal. Such an occurrence may be detected by comparing the two consecutive images, pixel by pixel. If the corresponding pixels differ by more than a given threshold then a counter is incremented. If the count over the entire frame exceeds a given threshold, the entire exposure is retained. Otherwise, it may be discarded.

Alternatively, after taking a picture at the i'th level of exposure, a picture at the k'th level is taken and compared with the picture taken at the i'th level, pixel by pixel. If they are different at more than a given number of pixels, then a picture is also taken at the intermediate exposure level j, which is between i and k. While taking the picture at the j'th exposure level the output can be compared with the outputs at both the i'th and k'th levels in order to determine whether any exposure between the j'th level and either the i'th level or the k'th level need be taken.

The foregoing techniques are intended to enable less than the full series of exposures to be employed. Normally one to three exposures are sufficient to provide a desired level of information.

Look Up Table (LUT) 16 pre-processes the digital video signal in accordance with program instructions received from a Host CPU 18. The Host CPU 18 is typically embodied in a personal computer communicating with the system hardware via a conventional serial or parallel link. Alternatively, the Host CPU 18 may be embodied in a relatively simple microcontroller, such as an Intel 8051 or a suitable custom-designed controller. As will be described more fully hereinbelow, the Host CPU defines input and output LUTs, camera exposures and transforms applied to the video signals.

The signal output from input LUT 16 is provided to a neighborhood transform processor (NTP) 20 which is operative to reduce the low frequency portions of the video data and to perform an edge enhancement transform on the video data received from input LUT 16. Timing control circuitry 22 supplies timing control signals to camera timing circuitry 12, input LUT 16, NTP 20, and to additional circuitry which will be described hereinbelow. The timing control circuitry 22 is operative to step the camera through various exposure levels, i.e. sensitivities. Preferably it may operate adaptively, by sensing the saturation and cut off limits and beginning at an exposure level intermediate therebetween, as described hereinabove.

Considering now the operation and structure of the neighborhood transform processor (NTP), it may be appreciated that according to one preferred embodiment of the invention, the NTP carries out a linear convolution. In such an embodiment, the NTP may comprise an off-the-shelf, special purpose VLSI chip, such as Zoran ZR33481 or ZR33881 Digital Filter Chips and some additional components, for example, delay lines and delay buffers, such as described in Zoran Technical Note No. Z.T.N. 03 entitled "Real Time Spatial Filtering with a Zoran DFP".

A typical function of the neighborhood transform processor in the above-described embodiment is to compute a new output value for each input pixel on the

which is supplied to image enhancement circuitry 76 such as a histogram equalizer 30 (FIG. 1).

Reference is now made to FIG. 4, which illustrates an alternative embodiment of video imaging system. Here, a plurality of cameras 80, each operative at a different exposure level or sensitivity, simultaneously acquires different versions of the same image at differing sensitivities. The video outputs of the cameras 80, which are all synchronized, are supplied to a pixel selector 82, which will be described hereinbelow.

The pixel selector is operative to provide a single output video signal having an extended dynamic range. For example, if each signal supplied to the pixel selector spans a 1:256 range (8 bits per pixel), the output of the pixel selector may span a range of 1:1,048,576 (20 bits per pixel). The output signal from the pixel selector 82 may be supplied to a neighborhood transform processor (NTP) 84, which may be identical to NTP 20, which reduces the dynamic range down to typically 1:256 (8 bits), while preserving substantial image contents and edge information. The output of NTP 84 may be supplied to image enhancement apparatus of the type described above, such as shown at reference numerals 28, 30 and 32 or employed without image enhancement as appropriate. Alternatively, the output of pixel selector 82 may be used in its full 20 bit format as an output 86.

The pixel selector employs a measurement correction algorithm based on the following:

Given a certain pixel  $P_{ij}$  is being sensed by a plurality of  $n$  cameras, which produce  $n$  different outputs for the light intensity of  $P_{ij}$ . If the exposure settings of the plurality of cameras is set such that each camera  $k$  is set to receive exactly one half of the light entering camera  $k+1$  for all  $k$  and assuming that the camera response to light is linear within a certain range, beyond which it is either saturated at high intensity or cut-off at low intensity, then

$$I_{ij}(k) + C = \frac{1}{2} I_{ij}(k+1)$$

where  $C$  is a constant offset term and  $I_{ij}(k)$  is the intensity at pixel  $ij$  for camera  $k$ , provided that both values of  $I$  are within the linear range of responsivity of the cameras.

If some light intensity value  $I_{ij}(m)$  is at or above the saturation value SAT, then

$$I_{ij}(k) = (\text{approximately}) \text{ SAT for all } k = m, m+1, \dots, n.$$

If some light intensity value  $I_{ij}(m)$  is at or below the cut-off value CUT, then

$$I_{ij}(k) = (\text{approximately}) \text{ CUT for all } k = 1, \dots, m-1.$$

Stated differently, the responsivity of the set of cameras to the light intensity of a given pixel is as shown in the graph of FIG. 5, which illustrates the aperture numerical aperture versus the Intensity  $I_{ij}$  for a given single pixel  $P_{ij}$ .

Pixel selection circuitry which will be described hereinbelow is operative to search along the graph of FIG. 5 for each set of received pixel intensities  $I_{ij}(1), I_{ij}(2) \dots I_{ij}(n)$  and to look for any one point on the linear segment, for example,  $I_{ij}(k)$  which comes from a camera  $k$ . It then transforms the intensity value  $I_{ij}(k)$  to the equivalent intensity which would have been measured

by camera  $n$ , if pixel  $P_{ij}$  were not causing saturation at camera  $n$ .

The transformation is as follows:

$$I_{ij}(n) = I_{ij}(k) \times 2^{(n-k)}$$

The foregoing may be generalized for a light intensity relationship  $1/R$  instead of  $\frac{1}{2}$  by replacing 2 by  $R$  throughout the above discussion.

Reference is now made to FIG. 6 which illustrates a preferred embodiment of pixel selector 82 arranged for operation with a plurality of boresighted and/or mutually synchronized cameras. Each of a plurality of digital comparators 100, typically of conventional construction, compares a signal from a camera with a signal from another camera whose value is multiplied by  $1/R$  in the general case or  $\frac{1}{2}$  in the specific example employed above. The outputs of comparators 100 pass through threshold circuits 102, such as to a priority encoder circuit 104. The output of the priority encoder circuit 104 controls a selector 106 which selects one of the inputs  $I(1) \dots I(n)$  and supplies it to a barrel shifter circuit 108. The barrel shifter circuit 108 receives a control input from a subtractor circuit 110.

The operation of the circuitry of FIG. 6 will now be explained briefly. The threshold circuits 102 which receive the outputs from comparators 100 provide outputs to circuitry 104 only from those comparators receiving signals within the linear range. Thus signals from outside the linear range are eliminated. This occurs, because the comparator 100 output is relatively high when the two inputs thereto are nearly the same, and is much lower when there is a significant difference therebetween.

The priority encoder circuit selects one of the signals from the linear range and employs that signal for scaling the corresponding intensity  $I(k)$  by the factor  $2^{(n-k)}$  as described above. Accordingly, the intensity output is unaffected by which camera records it. The priority encoder may be embodied in a TI SN 74148 chip.

Reference is now made to FIG. 7 which illustrates an alternative embodiment of image processor constructed and operative in accordance with an embodiment of the present invention. A single camera 120, provides an output to a 2 to 1 selector 122 and to a comparator 124. The output of the comparator passes through a threshold circuit 126, which outputs to combinational logic (CL) 128. The CL 128 outputs to a single bit per pixel frame buffer 130, which in turn outputs to the CL 128. The output of CL 128 is supplied as a control input to selector 122. The signal output from selector 122 is supplied via a frame buffer 132. The output from frame buffer 132 may be fed back via a multiply by two (or  $R$ ) circuit 134 to the selector 122 and to comparator 124 and is supplied as an output signal to a neighborhood transform processor (NTP) such as NTP 84 in the embodiment of FIG. 4. The output from frame buffer 132 may also serve as the system output, thus providing a full dynamic range output.

The apparatus of FIG. 7 corresponds to that shown in FIG. 6 for the use of a single camera. The apparatus of FIG. 7 is operative to sweep the sensitivity range over multiple successive acquisitions of the same image. The sensitivity sweep typically starts at the lowest sensitivity, i.e. the shortest integration time, for  $k=1$  and increases the sensitivity twofold in an exemplary case or  $R$ -fold in a generalized case, from one frame to the next until  $n$  frames are taken.

Accordingly, any given pixel may be in the cut-off region during the first few frames, then in the linear region, and then in the saturation region. Some pixels may be in only one or two of the three possible regions throughout the process (e.g. always saturated, or never saturated.)

At the outset frame buffer 130 is set to all zeros. When a pixel intensity  $I_{ij}(k)$  of the k'th image is output by the camera, it is compared with twice the value already stored in the frame buffer 132 of the same pixel ij by reading that value out and shifting it to the left by one bit (i.e. thus multiplying it by 2). If the values are different by more than a given predetermined tolerance level, indicating that the given pixel is still in the cut-off region, then the old value, already multiplied by two, is stored in the frame buffer 132. Otherwise, for example, if the pixel is in the linear region, the new value is stored and the ij bit of frame buffer 130 is set to one.

Once the ij bit of frame buffer 130 has been set to one, the decision is reversed. If the values are within a given predetermined tolerance, indicating that the pixel is in the linear region, then the new value is stored in the frame buffer. Otherwise, for example, if the pixel has reached saturation, the old value, already multiplied by two, is stored.

After all n frames are examined, the value stored for each pixel is the last one of the linear region, shifted left, (i.e. multiplied by 2,) the appropriate number of times. Thus all pixel intensities correspond to the computed value taken by a non-existing large dynamic range camera, operating at the sensitivity level of camera n.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described hereinabove. Rather the scope of the invention is defined only by the claims which follow:

We claim:

- 1. Wide dynamic range video imaging apparatus comprising:
  - sensor means for providing a plurality of video images of a scene at different exposure levels; and
  - means for processing the plurality of video images to produce a combined video image including image information from the plurality of video images by applying neighborhood transforms to the plurality of video images.
- 2. The video imaging apparatus of claim 1, wherein the means to process the plurality of video images comprises means for locally selecting the operating levels of the dynamic range of the combined video image within

the dynamic range of the sensor means, whereby the resulting video image includes image information from a plurality of video images with enhanced information content at local areas therein.

3. The video imaging apparatus of claim 1, wherein said means for processing the plurality of video images comprises means for highlighting edges in the combined video image.

4. The video imaging apparatus of claim 1, wherein said means for providing a plurality of video images comprises a single camera sequentially operated at a plurality of different exposure levels.

5. The video imaging apparatus of claim 1, wherein said means for providing a plurality of video images comprises a plurality of cameras each operating at a different exposure level.

6. The video imaging apparatus of claim 1, wherein said means for processing also comprises image enhancement means.

7. The video imaging apparatus of claim 6, wherein said image enhancement means comprises histogram equalization means.

8. The video imaging apparatus of claim 1, wherein the sensors can be area sensors or line sensors.

9. Wide dynamic range video imaging apparatus comprising:

means for receiving a plurality of video images of a scene at different exposure levels; and

means for processing the plurality of video images to produce a combined video image including image information from the plurality of video images by applying neighborhood transforms to the plurality of video images.

10. Wide dynamic range video imaging apparatus comprising:

sensor means for providing a plurality of video images of a scene at different exposure levels; and

means for processing the plurality of video images to produce a combined video image including image information from the plurality of video images by applying neighborhood transforms to the plurality of video images, said means comprising means for locally selecting the operating levels of the dynamic range of the combined video image within the dynamic range of the sensor means, whereby the resulting video image includes image information from the plurality of video images with enhanced information content at local areas therein.

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UNITED STATES PATENT AND TRADEMARK OFFICE  
CERTIFICATE OF CORRECTION

PATENT NO. :5,144,442  
DATED :September 1, 1992  
INVENTOR(S) :Ran Ginosar, et. al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title page, item [30], the date "Feb. 8, 1988" should read --  
Aug. 2, 1988 --.

On the Title page, item [63], "338,547" should read -- 388,547 --.

Signed and Sealed this  
Ninth Day of November, 1993

Attest:



BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks