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(54) **SIGNAL INTENSITY RANGE TRANSFORMATION APPARATUS AND METHOD**

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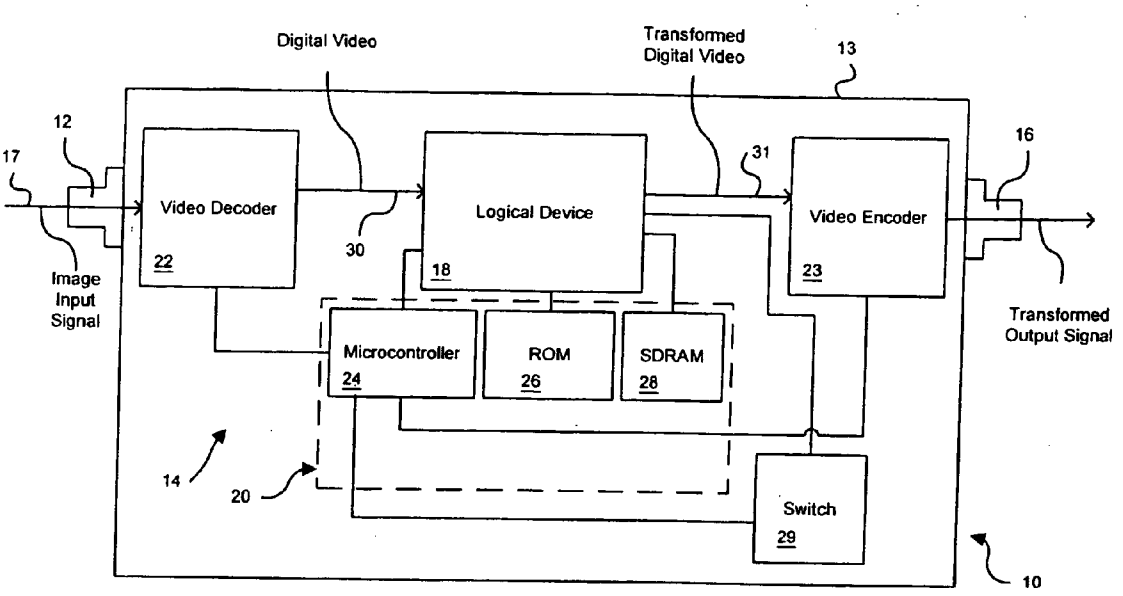
(52) **U.S. Cl.** **382/169**

(57) **ABSTRACT**

A system and method for manipulating image data is disclosed. Generally, the system and method identifies useful grey-levels within an input image. The image is then scaled based upon the identified useful grey-levels.



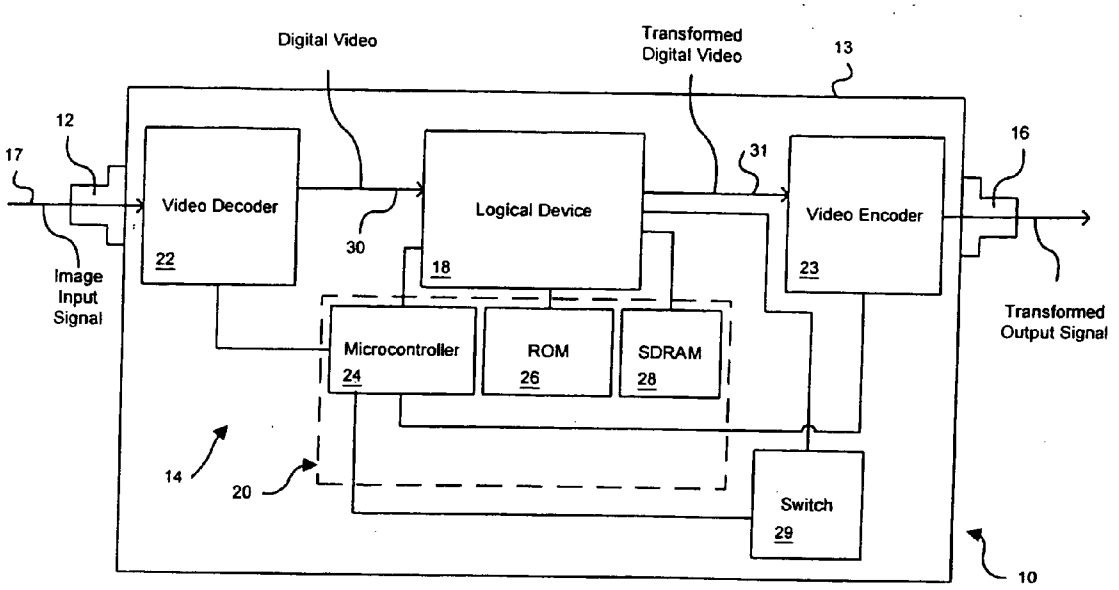


Figure 1

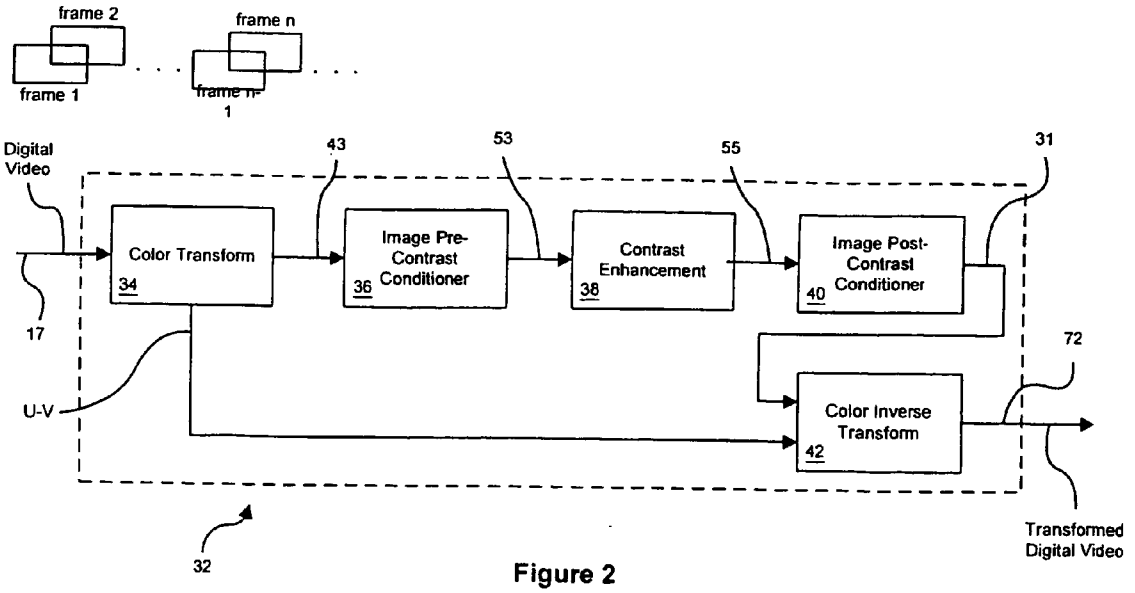


Figure 2

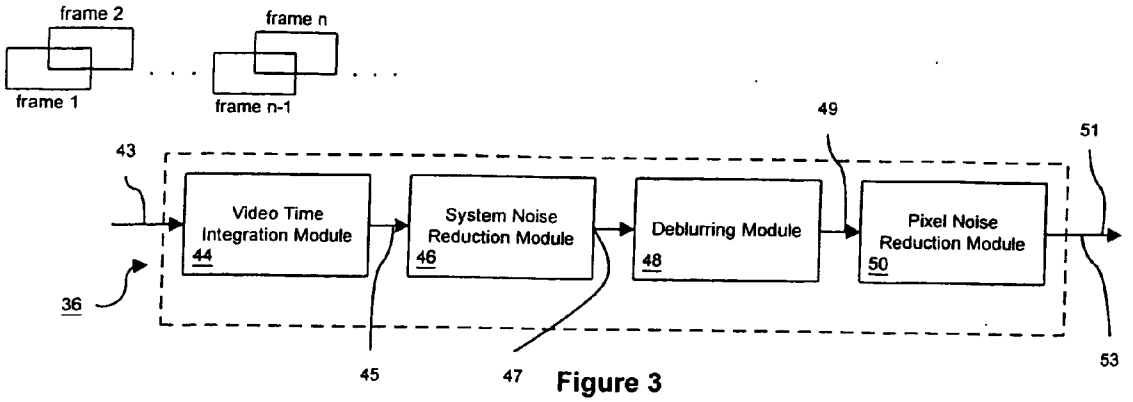


Figure 3

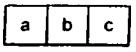


Figure 4(a)

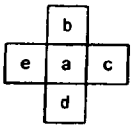


Figure 4(b)

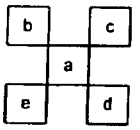


Figure 4(c)

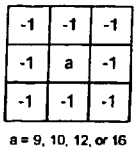


Figure 4(d)

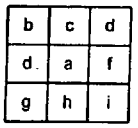


Figure 4(e)

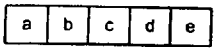


Figure 4(f)

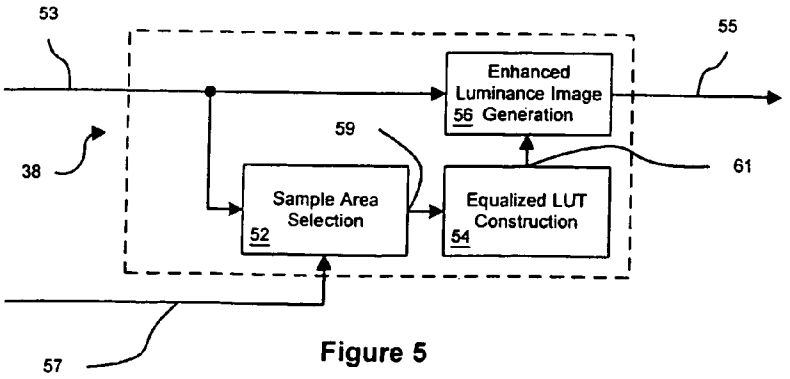


Figure 5

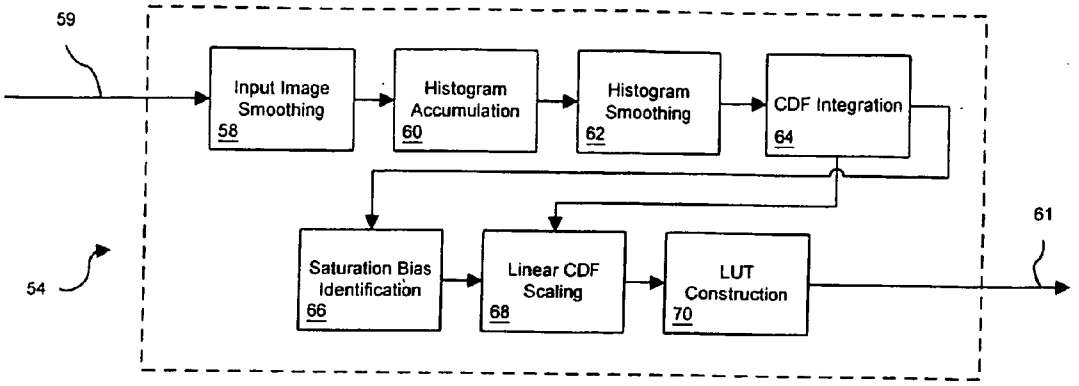


Figure 6

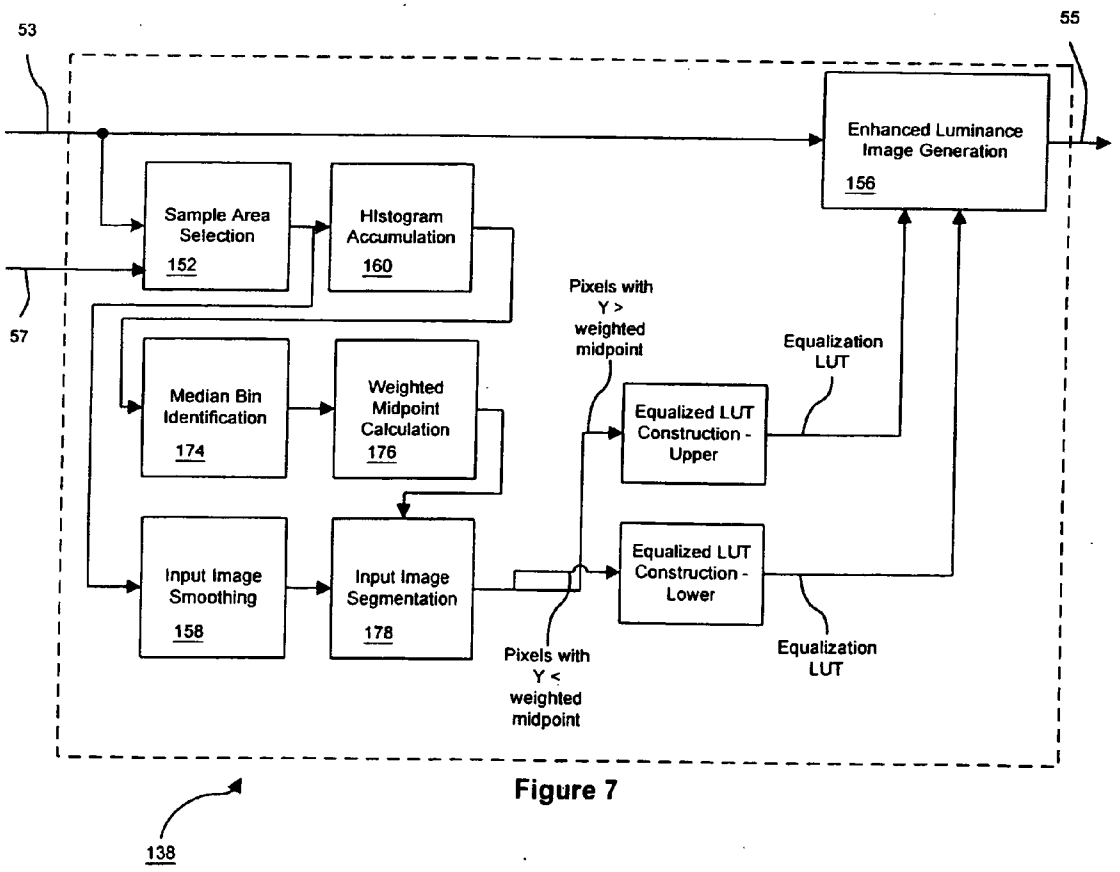


Figure 7

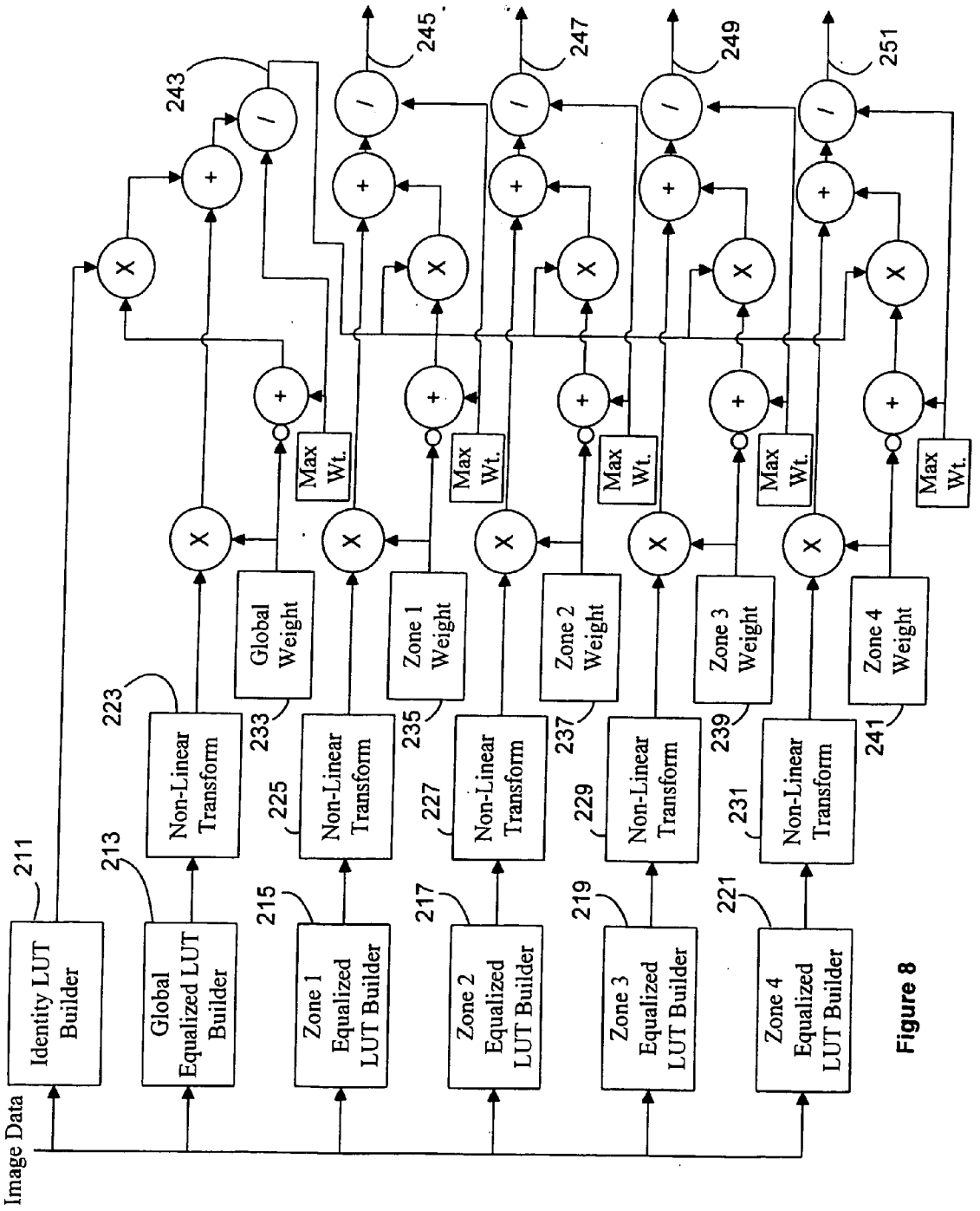


Image Data
Identity LUT Builder
211
Global Equalized LUT Builder
213
Zone 1 Equalized LUT Builder
215
Zone 2 Equalized LUT Builder
217
Zone 3 Equalized LUT Builder
219
Zone 4 Equalized LUT Builder
221
Non-Linear Transform
223
Non-Linear Transform
225
Non-Linear Transform
227
Non-Linear Transform
229
Non-Linear Transform
231
Non-Linear Transform
Global Weight
233
Zone 1 Weight
235
Zone 2 Weight
237
Zone 3 Weight
239
Zone 4 Weight
241
Max Wt.
243
245
247
249
251

Figure 8

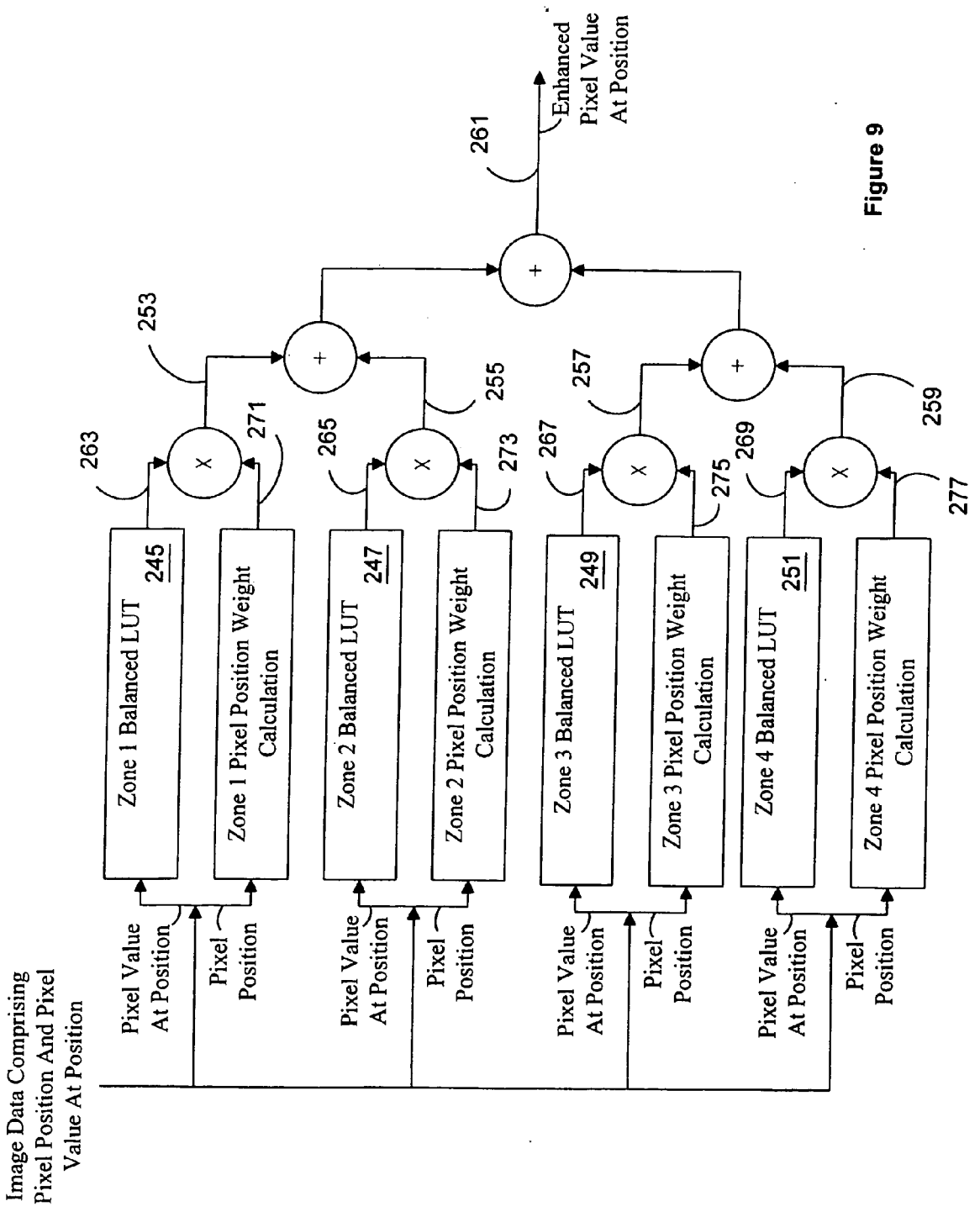


Image Data Comprising Pixel Position And Pixel Value At Position
Pixel Value At Position
Pixel Position
Zone 1 Balanced LUT
245
Zone 1 Pixel Position Weight Calculation
Zone 2 Balanced LUT
247
Zone 2 Pixel Position Weight Calculation
Zone 3 Balanced LUT
249
Zone 3 Pixel Position Weight Calculation
Zone 4 Balanced LUT
251
Zone 4 Pixel Position Weight Calculation
263
271
265
273
267
275
269
277
253
255
257
259
261
Enhanced Pixel Value At Position

Figure 9

SIGNAL INTENSITY RANGE TRANSFORMATION APPARATUS AND METHOD

RELATED APPLICATIONS

[0001] This application is a divisional application claiming the benefit of U.S. application Ser. No. 10/657,723 filed Sep. 8, 2003; which claims the benefit of U.S. Provisional Application No. 60/408,663, filed Sep. 6, 2002; the contents of both of these applications are herein incorporated by reference.

TECHNICAL FIELD

[0002] The present invention generally relates to imaging systems, and in particular, to a system for manipulating image data.

BACKGROUND OF THE INVENTION

[0003] Human interpretation of video or other imagery can be made difficult or even impossible by system noise, image blur, and poor contrast. These limitations are observed, for example, in most video and closed circuit television systems, and others, including such technology as RS-170 monochrome video, NTSC/PAL/SECAM video or digital color video formats.

[0004] Extreme lighting variation, for example, due to sunlight beams, can cause typical video cameras and imaging sensors to saturate (i.e., become unable to represent the real-world luminance range) resulting in wide-scale bright and dark regions having extremely low-contrast wherein objects are difficult or impossible to discern. At outdoor automated teller machines, for example, sunlight beams or strong lighting, in the background can cause a person in a dark area to become unidentifiable due to low contrast. This weakness is due to the limited luminance range of the imaging system.

[0005] The electronic iris and automatic gain control provided by some imaging systems are designed to try to optimally map the wide luminance values within a real-world light situation into a limited range digital representation, often resulting in a poor compromise. To adequately represent the bright areas, less illuminated areas become dramatically compressed in contrast and thus become very dark.

[0006] Besides having limited range, video or imagery from lower-cost imaging sensors can have significant noise due to a number of basic system limitations, as well as significant blur due to lower-cost, small, or simple optical configurations. Reducing noise and blur within these systems can improve the ability for a human viewer to effectively interpret image content.

[0007] Moreover, digital samples of interlaced analog video from a video field are typically taken by imaging systems. The noise inherent in such digital samples can make human interpretation of important details in the image difficult.

[0008] Hence, a need exists for a luminance range transformation apparatus and method that manipulates image data for improved interpretation thereof.

[0009] Others have provided some image post processing devices which can enhance contrast of an image. However, in many areas such as in security monitoring, real-time evaluation of images is highly beneficial or necessary. Accordingly, there is also a need to provide a luminance range transformation apparatus which can enhance an image in real-time or near-real time.

SUMMARY OF THE INVENTION

[0010] According to the present invention, a system and method has been developed that considers the mechanisms and defects of imagery from video or other sources to prescribe a sequence of tailored image processing operations designed to improve human interpretation of resulting images.

[0011] However, in a broad aspect of the invention, methods and devices are provided to redistribute discrete signal intensity values within groups of signal intensity values. The signal intensity values are supplied directly or indirectly from a sensor sensing an environment. It is proposed that the inventions can be used for enhanced interpretation of any array of signal intensities or variable values in any group of such values that have spatial or geometric relationships to one another (e.g. coordinates).

[0012] For example, the detailed disclosures below are directed to redistribution of grey-scale or luminance values in a rectilinear array (pixels) from a camera. It is also contemplated however, that the inventions may be applied to other values in a video image, such as redistribution of chrominance values. It is also proposed that the inventions may be employed with other sensing modalities such as, magnetic resonance imagery, radar, sonar, infrared, ultraviolet, microwave, X-ray, radio wave, and the like.

[0013] According to another aspect of the invention, the spatial scale of an entire group of signal intensity values are considered, for example, the luminance in an entire pixel image, so that the overall brightness from corner to corner is taken into account. In an orthogonal direction, all the frequency content of an image must be represented by the one global mapping, including the very lowest spatial frequency. Often, this single global mapping has to stretch to map all of the low frequency variation in the image, and then fails to enhance higher frequency structure of interest. The result can be a bright "bloom" on one side of the image, with too dark an area on the other side of the image. As such, there may not be optimal recognition of spatial structure because of the need to represent the large scale variation across the entire image.

[0014] It is proposed that to further improve overall contrast balance to reveal image structure at scales of interest by applying equalization at spatial scales representative of scales of interest. Accordingly, the inventions propose generating subset partitions of an image (group of signal intensities) representative of the spatial scales of interest. A transform mapping (e.g. of luminance) for the subsets of signal values is generated, so that a spatial scale (e.g., is ¼ of a global image for a quadrant subset) so as to mitigate or eliminate the lowest frequency from consideration. This improves representation of contrast for structures at this scale.

[0015] Computing a luminance transformation at every pixel (with for example a filter kernel) for a neighborhood around that pixel, would result in a large computational

burden because the resulting spatial scales are too small. In contrast, the present invention employs accumulating pixel samples across larger "right-sized" spatial scales, while using efficient interpolation to produce the correct transform (e.g. for luminance) representation at each pixel.

[0016] According to another aspect of the invention, apparatus and methods include: decomposing a group of signal values into subgroup partitions from which to sample values and construct associated transforms and to combine those transform values at every coordinate (e.g. pixel) according to a rule which weights the contribution of each mapping in accordance with "image" geometry and value coordinate or position.

[0017] According to another aspect of the invention, apparatus and methods are provided for blending transformed values from the global set of values (e.g. entire pixel image) with transformed values from the spatial segments to adjust contributions from several spatial scales as desired.

[0018] While overall interpretation of groups of signal intensity values is provided according to the invention, it is of particular note that the effectively mitigate signal values which are out of limit for a sensor system, for example, saturated sensor response.

[0019] In a preferred embodiment for enhancing luminance contrast in video signals, preferred operations can include digital sampling and luminance/color separation, noise reduction, deblurring, pixel noise reduction, histogram smoothing, contrast stretching, and luminance and chrominance re-combination. One or more of the operators can have configurable attributes, such as degree of noise reduction, brightness, degree of deblurring, and determined range of useful grey-levels.

[0020] Other advantages and features of the present invention will be apparent from the following description of a specific embodiment illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0021] FIG. **1** is a simplified block diagram of a device in accordance with the present invention, including a logical device;

[0022] FIG. **2** is a simplified functional block diagram of a process performed by the logical device of FIG. **1**, the process having a color transform, an image pre-contrast conditioner, a contrast enhancement, an image post-contrast conditioner, and a color inverse transform;

[0023] FIG. **3** is a simplified functional block diagram of the image pre-contrast conditioner of FIG. **2**, the pre-contrast conditioner comprising a system noise reduction filter, a deblurring module, and a pixel noise reduction module;

[0024] FIGS. **4**(*a*)-(*f*) depict various exemplary kernels shapes that can be used with the system noise reduction filter, deblurring module, and pixel noise reduction module of FIG. **3**;

[0025] FIG. **5** is a simplified functional block diagram of the contrast enhancement block of FIG. **2**, the contrast enhancement comprising an equalized lookup table construction block and an enhanced luminance image generation block;

[0026] FIG. **6** is a simplified functional block diagram of the equalized lookup table construction block of FIG. **5**;

[0027] FIG. **7** is a simplified functional block diagram of another embodiment of the contrast enhancement block of FIG. **2**; and,

[0028] FIGS. **8** and **9** is a simplified function block diagram of yet another embodiment of the contrast enhancement block of FIG. **2**.

DETAILED DESCRIPTION

[0029] This invention is susceptible of embodiments in many different forms. For example, the methods and apparatus disclosed there is shown in the drawings and will herein be described in detail, a preferred embodiment of the invention. The present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiment illustrated.

[0030] Referring now to the drawings, and as will be appreciated by those having skill in the art, each of the FIGURES depicts a simplified block diagram wherein each block provides hardware (i.e., circuitry), firmware, software, or any combination thereof that performs one or more operations. Each block can be self-contained or integral with other hardware, firmware, or software associated with one or more other blocks.

[0031] Turning particularly to FIG. **1**, a device **10** is disclosed for enhancing, through transformation, the luminance range of an image input signal. The device **10** includes an input connector **12**, logic circuitry **14**, and an output connector **16**. The connectors **12** and **16** are mounted in a conventional manner to an enclosed housing **13**, constructed of a metal, metal alloy, rigid plastic, or combinations of the above, that contains the logic circuitry **14**. In one embodiment, one or more of the modules described herein are performed by the logic circuitry **14** comprising of one or more integrated circuits, commonly referred to as "ICs," placed on one or more printed circuit boards mounted within the housing **13**.

[0032] Preferably, the device **10** is a stand-alone or embedded system. As used herein, the term "stand-alone" refers to a device that is self-contained, one that does not require any other devices to perform its primary functions. For example, a fax machine is a stand-alone device because it does not require a computer, printer, modem, or other device. Accordingly, in an embodiment, the device **10** does not need to provide ports for connecting a disk drive, display screen, or a keyboard. However, in an alternative embodiment, the device **10** could provide one or more ports (e.g., RS-232) for supporting field interactivity.

[0033] Also, as used herein, an embedded system is a system that is not a desktop computer or a workstation computer or a mainframe computer designed to admit facile human interactivity. Another delineator between embedded and "desktop" systems is that desktop systems (and workstation, etc.) present the status of the computer state to the human operator via a display screen and the internal state of the computer is represented by icons on the screen, and thus the person can interact with the computer internal state via control of the icons. Moreover, such a computer uses a software layer called an "operating system" through which

the human operator can interact with the internal state of the computer. Conversely, with an embedded system, while it is performing its work function, the human operator cannot interact with the work process except to stop it.

[0034] The input connector **12** provides for operably connecting the device **10** to an image input signal **17** generated by a video camera (not shown), or the like, having a video output. In one embodiment, the input connector **12** consists of an F connector, BNC connector, RCA jacks, or the like. The input connector **12** is operably connected to the logic circuitry **14** by way of a conductive path attached to the input connector and the printed circuit board contained within the housing **13**. The logic circuitry could also be coupled through other than a conductive path such as through optical coupling.

[0035] Preferably, but not necessarily, the image input signal **17** is a conventional analog video signal containing a plurality of still images or fixed image frames taken in a sequential manner. Each frame provided by the image input signal is also referred to herein as an image input frame. Each image or frame includes data regarding an array of pixels contained therein.

[0036] The output connector **16** of the device **10** provides for connecting the device to an output device such as a monitor (not shown). Like the input connector **12**, the output connector **16** consists of any means for outputting the signal to other devices such as, an F connector, BNC connector, RCA jacks, or the like. The output connector **16** is operably connected to the logic circuitry **14** by way of a conductive or coupled path attached to the output connector and the printed circuit board contained within the housing **13**. As explained in detail further herein, the output signal provided by connector **16**, and thus the device **10**, provides an output signal which includes data resulting from transforming or other operations carried out with respect to image input signal **17** received ("transformed output signal"). The output signal can include a plurality of image output frames and be formatted as a conventional analog video signal, a digital signal, or the like. For example, but by no means exclusive, the output signal can be in a format as defined by NTSC, VGA, HDTV, or other desired output formats.

[0037] In one embodiment, the logic circuitry **14** within the device **10** includes, inter alia, circuitry configured to transform the variable range of grey-scale values in the image input signal **17** received by the input connector **12**. Preferably, the logic circuitry **14** includes a logical device **18** with corresponding support circuitry **20**, a video decoder **22**, and a video encoder **23**. The support circuitry **20** preferably includes a microcontroller **24**, a read only memory **26**, and a random access memory **28** comprising a synchronous dynamic random access memory.

[0038] In an embodiment, an optional switch **29** is provided for configuring the logic circuitry **14** within the device **10**. The switch **29** is operably connected to the microcontroller **24** and logical device **18**. The switch **29** allows a user to enable or disable, features or processes provided by the logic circuitry **14** within the device **10**. In one embodiment, the switch **29** consists of a conventional DIP switch. In an alternative embodiment, the configuration of the circuitry **14** within the device **10** is hardwired, or can be set via software commands, instead of using a switch.

[0039] Preferably, video decoder **22** is operably connected to the input connector **12** and the logical device **18**. Accordingly, the video decoder **22** receives the image input signal **17** that can consist of live video from a television broadcast, a video tape, a camera, or any other desired signals containing or representing image content. The video decoder **22** preferably is a conventional device for tracking the video image input signal **17**, digitizing the input signal (if required), separating out the brightness and color information from the input signal, and forwarding the digital video signal **30** to the logical device **18** on a frame by frame basis.

[0040] In one embodiment, the input image signal **17** received by the video decoder **22** is an analog signal formatted in a predefined manner such as PAL, NTSC, or another conventional format. The video decoder **22** converts the analog signal **17** into a digital video signal **30** using a conventional analog-to-digital conversion algorithm. Preferably, the digital video signal **30** provided by the video decoder **22** includes luminance information and color information in any conventional manner such as, specified by YUV format, YCbCr format, super video, S-video, or the like. Alternatively, the digital video signal **30** can have the luminance information embedded therein such as that provided by digital RGB, for example.

[0041] In one embodiment, the video decoder **22** is capable of converting a plurality of different analog video formats into digital video signals suitable for processing by the logical device **18** as described in detail further herein. In one embodiment, the microcontroller **24** configures the video decoder **22** for converting the image input signal **17** into a digital video signal **30** having a specific format type (e.g., CCIR601, RGB, etc.). If desired, the microcontroller **24** determines the format of the image input signal **17**, and configures the video decoder **22** accordingly. The determination can be accomplished by the microcontroller **24** checking the user or device manufacturer configured settings of the DIP switch corresponding with the format of the image input signal **17** expected to be received. Alternatively, the video decoder **22** can include circuitry for automatically detecting the format of the image input signal **17**, instead of using preset DIP switch settings.

[0042] Preferably, the gain of the video decoder **22** is set to reduce overall contrast on the luminance for reducing the probability of image saturation. In an alternative embodiment, the video decoder **22** provides a fixed bit resolution output range (e.g., 8 bit, 16 bit, 32 bit, etc.) and a digitizer maps the image input signal in a conventional manner for effective use of the resolution output range. Preferably, the full range of the digitizer output is utilized.

[0043] Turning to the logical device **18**, as will be understood by those having skill in the art, the logical device receives digital video signals **30** and provides digital output signals **31** (i.e., transformed pixel array or frame data) in response to the digital video signals **30**. As indicated previously, in one embodiment, the device **10** receives analog image input signals **17** that are converted by the video decoder **22** into digital video signals **30** for manipulation by the logical device **18**. Moreover, as explained in detail further herein, the digital output **31** of the logical device **18** can be converted (if desired) into an analog output by the video encoder **23** connected between the logical device **18** and the output connector **16**.

[0044] Preferably, the logical device **18** consists of a conventional field programmable gate array (FPGA). How-

ever, the logical device **18** can consists of a Digital Signal Processor (DSP), a microcontroller, an Application Specific Integrated Circuit (ASIC), or other suitable device.

[**0045**] In an alternative embodiment, instead of receiving analog input signals **17**, the device **10** can receive digital image input signals that are provided, without any conversion, to the logical device **18**. Thus, in this alternative embodiment, the video decoder **22** can be omitted.

[**0046**] Regardless of whether a video encoder or decoder is provided, it is to be understood that the logical device **18** is operably connected between connectors **12** and **16**. Accordingly, an image input signal enters the input connector **12**, is modified by the logical device **18**, and then exits via the output connector **16** as a transformed output signal. Preferably, the frame output rate of the device **10** is substantially equal to the frame input rate to the device. The device **10** provides an output of thirty frames per second in response to a frame input rate of thirty frames per second.

[**0047**] In one embodiment, the logical device **18** provides a sequence of image processing functional modules or blocks **32** within a process as illustrated in FIG. **2**. In one embodiment, the blocks **32** represent a color transform **34**, an image pre-contrast conditioner **36**, a contrast enhancement **38**, an image post-contrast conditioner **40**, and a color inverse transform **42**.

[**0048**] Each of the modules **32** preferably performs a specific functional step or plurality of functional steps as described in detail further herein. Turning back to FIG. **1**, static data for configuring the logical device **18**, if needed or desired, is stored within the read only memory **26** operably connected thereto. As appreciated by those having skill in the art, the read only memory **26** provides for storing data that is not alterable by computer instructions.

[**0049**] Storage for data manipulation and the like is provided by the synchronous dynamic random access memory (SDRAM) **28**. Preferably, a high speed random access memory is provided by the support circuitry **20** to reduce performance bottlenecks. In one embodiment, the memory **20** is used as a field buffer.

[**0050**] Turning back to FIG. **2**, the color transform **34** provides for separating the luminance from the digital video signal **30**, as desired. In one embodiment, the digital video signal **30** provided by the video decoder **22** consists of a digital RGB signal. As such, luminance information is not separated from color information. Thus, the color transform **34** provides for separating the luminance information for each pixel, within each frame, from the digital video signal **30**.

[**0051**] Preferably, the color transform **34** uses a conventional algorithm for converting a digital RGB video input signal into a Yuv format signal, YCbCr format signal, or other desired format signal. Accordingly, the color transform **34** provides an output comprising three channels: luminance **43**, and U-V or other values ascribed per pixel location.

[**0052**] In an alternative embodiment, the digital video signal **30** provided by the video decoder **22** consists of a super video or S-video. As such, the digital video signal **30** consists of two different signals: chrominance and luminance. Accordingly, the color transform **34** can be omitted from the process of FIG. **2** because the luminance **43** is separately provided by the S-video input.

[**0053**] It should be understood as noted above, that a separate channel or channels (not shown) comprising the steps to be discussed below with respect to luminance information, could be provided to any one of RGB/chrominance values independently for transforming the values and redistributing the color values in the image.

[**0054**] As shown in FIG. **2**, the luminance information **43** contained within the digital video signal **30** is received by the image pre-contrast conditioner **36**. As shown in FIG. **3**, the image pre-contrast conditioner **36** can include a video time integration module or block **44**, a system noise reduction module or block **46**, a deblurring module or block **48**, and a pixel noise reduction module or block **50**. As will be appreciated by those having ordinary skill in the art, any one or all of the blocks within FIG. **3** can be omitted including, but not limited to, the video time integration module **44**.

[**0055**] In one embodiment, the video time integration module **44** consists of a low-pass filter for noise reduction of the luminance signal **43**. As understood by those having skill in the art, each frame includes an array of pixels wherein each pixel has a specific i,j coordinate or address. Noise reduction by the video time integration module **44** is preferably achieved by combining the current frame (n) with the immediately preceding frame (n−1) stored by the logical device **18** within the memory **28**. Desirably, for each pixel c(i,j) in the current image frame (n), the corresponding pixel p(i,j) from the preceding captured frame (n−1) is subtracted to result in a difference d(i,j). The absolute value of the difference d(i,j) is determined, and compared to a predetermined threshold value. If the absolute value of the difference d(i,j) is greater than the predetermined threshold, then the time integration output signal **45** of the video time integration module **44** is c(i,j). Otherwise, the time integration output signal **45** of the video time integration module **44** is the average of c(i,j) and p(i,j).

[**0056**] As indicated above, the video time integration module **44** can operate such that object motion, which ordinarily creates large pixel differences, are represented by current pixels while background differences due to noise are suppressed by the averaging. Accordingly, the video time integration module **44** provides for avoiding image blurring as a result of low-pass spatial domain filtering on the current image.

[**0057**] In one embodiment, the median filter or system noise reduction module **46** receives the time integration output signal **45** (i.e., transformed pixel frame data) and, in response thereto, provides for reducing pixel noise caused by the system sensor (e.g., camera), electromagnetic, and/or thermal noise. The median filter **46** can include a user selectable level of noise reduction by selecting from a plurality of filter kernels via DIP switch **29**, or the like, operably coupled to the logical device **18**. The filter kernel applied by the noise reduction module **40** to the current frame, as preferably modified by time integration module **44**, is designed to achieve noise reduction while minimizing the adverse effect of the filter on perceived image quality. For instance, a 3.times.1 kernel (FIG. **4**(*a*)) provides for a reduction in row noise due to the kernel shape, while having minimal adverse effect on the image. Also, a 5-point or plus kernel (FIG. **4**(*b*)) offers symmetric noise reduction with low

adverse impact to image quality. Moreover, a hybrid median filter (FIG. **4**(*c*)) offers symmetric noise reduction with lower adverse impact than the full 3.times.3 kernel. In one embodiment, a user or the manufacturer can select from the kernel shapes shown in FIGS. **4**(*a*)-(*c*).

[**0058**] The deblurring module or block **48** provides for counteracting image blurring attributable to the point spread function of the imaging system (not shown). In an embodiment, the deblurring module or block **48** uses a Laplacian filter to sharpen the output **47** (i.e., transformed pixel frame data) received from the filter **46**. The deblurring module or block **48** can include a user-selectable level of image sharpening from a plurality of Laplacian filter center pixel weights. In one embodiment, the user or manufacturer can select the center pixel weight via the DIP switch **29** operably coupled to the logical device **18**.

[**0059**] Preferably, the Laplacian filter uses a 3.times.3 kernel (FIG. **4**(*d*)) with selectable center pixel weights of 9, 10, 12, or 16, requiring normalization divisors of 1, 2, 4, or 8, respectively. As shown in FIG. **4**(*d*), the remaining kernel pixels are preferably assigned a weight of −1. The result of applying the kernel is normalized by dividing the convolution result for the current pixel element by the normalization divisor.

[**0060**] As will be appreciated by those having ordinary skill in the art, the deblurring module or block **48** can use other filters in place of a Laplacian type filter. In an embodiment, and in like fashion to the use of the Laplacian filter with various weights, a general filter with kernel as shown in FIG. **4**(*e*) can be used for deblurring.

[**0061**] The output **49** (i.e., transformed pixel frame data) of the deblurring module **48** emphasizes isolated pixel noise present in the input image signal. Preferably, the pixel noise reduction module **50** provides for reducing isolated pixel noise emphasized within the output **49** of the deblurring module **48**. In one embodiment, the pixel noise reduction module **50** employs a small-kernel median filter (i.e., small pixel neighborhood such as a 3.times.3) to reduce isolated pixel noise. The pixel noise reduction filter or module **50** can provide a user or manufacturer selectable level of noise reduction by allowing for the selection from a plurality of filter kernels. In a preferred embodiment, the DIP switch **29**, software, or the like, is used to select from a five-point "plus patterned" kernel (FIG. **4**(*b*)) or a hybrid median filter such as (FIG. **4**(*c*)).

[**0062**] As shown in FIG. **2**, the contrast enhancement module or block **38** enhances the contrast of the conditioned luminance signal **53** (i.e., transformed pixel frame data) provided by the image pre-contrast conditioner **36** in response to the original luminance input signal **17**. In an alternative embodiment, no image pre-contrast is provided. Instead, the contrast enhancement module **38** directly receives the image input signal **17**, and in response thereto, generates an enhanced image signal **55**.

[**0063**] Turning to FIG. **5**, the contrast enhancement module or block **38** preferably includes a sample area selection module or block **52**, an equalized lookup table construction module or block **54**, and an enhanced luminance generation module or block **56**. As used herein, and as will be appreciated by those having ordinary skill in the art after reading this specification, the phrases "lookup table" and "equalized lookup table" both refer to a lookup table derived from grey-level values or a lookup table representative of the inversion of the cumulative distribution function derived from an accumulated histogram.

[**0064**] In one embodiment, the sample area selection module or block **52** receives the conditioned luminance image signal **53** provided by the image pre-contrast conditioner **36** (FIGS. **2** and **3**) and a selected portion of the input image, via input **57**, to be enhanced. In response to the conditioned luminance input signal **53** and the image portion selection **57**, the sample area selection module provides a selected conditioned luminance image signal **59** comprising conditioned luminance pixel data from the pixels within the selected region.

[**0065**] Depending upon the overall embodiment of a system, the selected portion of the image can be selected in a conventional manner such as by using a point-and-click interface (e.g., a mouse) to select a rectangular sub-image of an image displayed on a monitor (not shown). Alternatively, the selected portion of the image can be selected by automated means such as by a computer, based upon movement detection, with a portion of the image or other criteria.

[**0066**] In one embodiment, the equalized look-up table construction module or block **54** receives the selected conditioned image signal **59** from the sample area selection module or block **52** and, in response thereto, provides for creating a lookup table **61** that is used in generating the enhanced image signal **55** (i.e., transformed pixel frame data). As previously indicated, the selected conditioned luminance signal **59** received from the sample area selection module or block **52** can be a sub-image comprising a portion of the overall conditioned luminance image signal **53** received from the image pre-contrast conditioner **36** (FIGS. **2** and **3**). Alternatively, the selected conditioned luminance signal **59** can consist of the complete conditioned luminance signal **53**, without any apportioning by the sample area selection module **52**.

[**0067**] As shown in FIG. **6**, the equalized lookup table construction module, or block **54** of FIG. **5**, includes an input smoothing module or block **58**, a histogram accumulation module or block **60**, a histogram smoothing module or block **62**, a cumulative distribution function integration module or block **64**, a saturation bias removal module or block **66**, a linear cumulative distribution function scaling module or block **68**, and a lookup table construction module or block **70**.

[**0068**] In one embodiment, the input image smoothing module, or block **58**, receives the selected conditioned luminance image signal **59** and, in response thereto, generates a smoothed conditioned luminance image signal on a frame-by-frame basis. Preferably, the input image smoothing module or block **58** applies a Gaussian filter with a traditional 3.times.3 kernel to the selected signal **59** for smoothing the image within each frame. As recognized by those having skill in the art, the Gaussian filter performs a weighted sum (center pixel=highest weight), wherein the result is normalized by the total kernel weight.

[**0069**] In one embodiment, a histogram accumulation module, or block **60**, provides for generating a histogram of the selected conditioned image signal **59**, as modified by the input image smoothing module. The histogram accumula-

tion module, or block **60**, accumulates a conventional histogram from the received input. Accordingly, the histogram can be used to provide a graph of luminance levels to the number of pixels at each luminance level. Stated another way, the histogram reflects the relationship between luminance levels and the number of pixels at each luminance level.

[**0070**] Accordingly, the histogram accumulation module or block **60** includes a plurality of data storage locations or "bins" for tracking the number of occurrences of each grey-level occurring in the received input signal, for example, such as that received by block **58**. Preferably, the histogram accumulation module or block **60** includes a bin for every discrete grey-level in the input signal. As stated previously, for each grey-level in the input signal, the histogram accumulation module or block **60** determines the number of pixels in the input luminance image with the corresponding grey-level after being filtered, if desired. Accordingly, the histogram result for any given grey-level k is the number of pixels in the luminance image input having that grey-level.

[**0071**] In one embodiment, the histogram smoothing module or block **62** provides for reducing noise in the histogram created from the input image. The histogram smoothing module, or block **62**, receives the histogram from the histogram accumulation, module or block **60**, and in response thereto, generates a smoothed histogram. Preferably, the histogram smoothing module or block **62** applies a 5-point symmetric kernel (FIG. **4**(*f*)) to filter the histogram calculated for each frame.

[**0072**] In one embodiment, the cumulative distribution function integration module or block **64** provides for integrating the histogram to create a cumulative distribution function. The cumulative distribution function integration module or block **64** receives the histogram from the histogram smoothing module **62**, or optionally from the histogram accumulation module **60**. The cumulative distribution function integration module **64** integrates the received histogram to generate a cumulative distribution function. It has been observed that integrating a smoothed histogram can result in a cumulative distribution function having an increased accuracy over a cumulative distribution function resulting from an unsmoothed histogram.

[**0073**] The cumulative distribution function integration module or block **64** includes a plurality of data storage locations or "bins" which hold the cumulative distribution function result for each input grey-level. Preferably, the cumulative distribution function integration module, or block **64**, includes a bin for every discrete grey-level in the image resolution input range. For each grey-level in the image resolution input range, the cumulative distribution function integration module or block **64** determines the cumulative distribution function result and stores that result in the bin corresponding to that grey-level. For each grey-level k, the cumulative distribution function result is the sum of the histogram value for grey-level k and the cumulative distribution function result for the previous grey-level k−1. Accordingly, the following equation describes the cumulative distribution function result for a given grey-level k:

$$CDF(k)=H(k)+CDF(k-1)$$

[**0074**] where CDF(k) is the cumulative distribution function result for grey-level k, H(k) is the histogram value for grey-level k, and CDF(k−1) is the cumulative distribution function result for the grey-level one increment lower than grey-level k.

[**0075**] The saturation bias identification module, or block **66**, provides for identifying the grey-levels that bound the useful information in the luminance signal **43**. In one embodiment, the saturation bias identification module **66** receives the cumulative distribution function from the cumulative distribution function integration module **64** and determines the grey-levels at which the first unsaturated grey-level, k.sub.f, and the last unsaturated grey-level, k.sub.**1**, occurs. The first unsaturated grey-level, k.sub.f, is determined by identifying the first grey-level k.sub.**0** for which the cumulative distribution function returns a non-zero value. The grey-level k.sub.**0** is treated as saturated, and the saturation bias identification module **66** identifies k.sub.f as the sum of k.sub.**0** plus one additional grey-level. The last unsaturated grey-level, k.sub.**1**, is determined by identifying the first grey-level k.sub.n for which the cumulative distribution function returns the number of pixels in the image. The grey-level k.sub.n is treated as saturated, and the saturation bias identification module or block **66** identifies k.sub.**1** as the difference between k.sub.n minus one additional grey-level.

[**0076**] Accordingly, the useful grey-levels identified by the saturation bias identification module **66** is the range from, and including, k.sub.**0** plus one additional grey-level through k.sub.n minus one additional grey-level. In another embodiment, the useful grey-levels identified by the saturation bias identification module **66** is the range from, and including, k.sub.**0** through k.sub.n minus one additional grey-level. In yet another embodiment, the useful grey-levels identified by the saturation bias identification module **66** is the range from, and including k.sub.**0** plus one additional grey-level through k.sub.n. In a further embodiment, the useful grey-levels identified by the saturation bias identification module **66** is the range from, and including, k.sub.**0** plus X additional grey-level(s) through k.sub.n minus Y additional grey-level(s), wherein X and Y are whole numbers greater than zero.

[**0077**] The linear cumulative distribution function scaling module or block **68** provides for scaling the portion of the cumulative distribution function corresponding to the unsaturated, useful grey-levels in the luminance input image across the entire range of cumulative distribution function grey-level inputs. In a preferred embodiment, the linear cumulative distribution function scaling module **68** receives the cumulative distribution function, provided by the cumulative distribution function integration module **64**, and the first unsaturated grey-level k.sub.f and the last unsaturated grey-level k.sub.**1** from the saturation bias identification module **66**.

[**0078**] The linear cumulative distribution function scaling module **68** includes a plurality of data storage locations or "bins" equal to the number of bins in the cumulative distribution function for holding the linearly mapped cumulative distribution function result for each input grey-level. In a preferred embodiment, the cumulative distribution function scaling module **68** scales the portion of the cumulative distribution function between k.sub.f and k.sub.**1** inclusively across the entire range of the linearly scaled cumulative distribution function. Accordingly, for each

grey-level k in the input range, the linearly scaled cumulative distribution function output value LCDF(k) is determined by the following equation:

$$LCDF(k)=(CDF(k)-CDF(kf))/(CDF(Kl)-CDF(Kf))$$

[0079] where CDF(k) is the cumulative distribution function result for grey-level k, CDF(kf) is the cumulative distribution function result for kf, and CDF(kl) is the cumulative distribution function result for kl. Each linearly mapped cumulative distribution function result is stored in the bin corresponding to the current grey-level k. If LCDF(k) is negative for any input grey-level k, the linearly scaled cumulative distribution function result in the bin corresponding to the input grey-level k is set to zero.

[0080] The determination of the cumulative distribution function output value can be calculated using known methodologies for improving computation ease. For instance, the numerator can be scaled by a multiplier, before the division operation, to obtain proper integer representation. The result of the division can then be inversely scaled by the same multiplier to produce the LCDF(k) value. Preferably, the scale factor is an adequately large constant, such as the number of pixels in the input image.

[0081] In one embodiment, the lookup table construction module or block **70** generates a lookup table **61** that is used by the enhanced luminance image generation module (FIG. **5**) to produce the enhanced luminance image signal **55**. The lookup table construction module **70** receives the linearly scaled cumulative distribution function from the linear cumulative distribution function scaling module **70**. In response to the scaled cumulative distribution function, the lookup table construction module **70** provides the lookup table **61**.

[0082] Preferably, the lookup table **61** is constructed by multiplying each linearly scaled cumulative distribution function result by the number of discrete grey-levels in the output image resolution range which can be provided by the DIP switch **29** (FIG. **1**), software, or other desired means. If the multiplication result is greater than the maximum value in the output image resolution range for any input grey-level, the linearly scaled cumulative distribution function result for that input grey-level is set to the maximum value in the output image resolution range. Accordingly, for each grey-level input in the linearly scaled cumulative distribution function, the result is a value in the output image resolution range.

[0083] Turning back to FIG. **5**, the enhanced luminance image generation module, or block **56**, is responsive to the lookup table **61** and the conditioned luminance signal **53**. The luminance of each pixel within each input frame can be reassigned a different value based upon the lookup table corresponding to the same frame. Stated another way, the luminance value for each pixel in the conditioned luminance input image is used as an index in the look-up table, and the value at that index location is used as the luminance value for the corresponding pixel in the enhanced luminance output image. The reassigned frame data is then forwarded, preferably to image post contrast conditioner **40**, as the enhanced image signal **55**.

[0084] As shown in FIG. **2**, the image post contrast conditioner **40** provides for filtering the enhanced image signal **55** to generate an enhanced conditioned image signal **72**. The conditioner **40** can apply to the image signal **55** one or more conventional imaging filters, including an averaging filter, a Gaussian filter, a median filter, a Laplace filter, a sharpen filter, a Sobel filter, and a Prewitt filter.

[0085] The color inverse transform **42** generates the contrast enhanced digital video output signal **31**, having an expanded range, in response to the enhanced image signal **72** and the color information for the same frame. The enhanced image signal and color information are combined in a conventional manner wherein luminance is combined with color information.

[0086] As will be appreciated by those having skill in the art, while the luminance of the input signal is being enhanced, the color information can be stored within memory **28**, for example. Once the luminance has been enhanced, it can be re-combined with the color information stored in memory.

[0087] In response to the digital video output signal **31**, the video encoder **23** preferably provides an analog output signal via output connector **16**. The video encoder **23** preferably utilizes conventional circuitry for converting digital video signals into corresponding analog video signals.

[0088] Turning to FIG. **7**, an alternate embodiment of the contrast enhancement module is depicted. Within FIG. **7**, that last two digits of the reference numbers used therein correspond to like two digit reference numbers used for like elements in FIGS. **5** and **6**. Accordingly, no further description of these elements is provided.

[0089] The median bin identification module or block **174** determines the median of the histogram provided by the histogram accumulation module **160**. Next, the brightness midpoint value is calculated by the weighted midpoint calculation module or block **176**. The brightness midpoint value preferably is calculated as the weighted sum of the actual grey-level midpoint of the input frame and the median of the input distribution. Preferably, the weights assigned to the grey-level midpoint and the median of the input distribution are configured as compile-time parameters.

[0090] The image segmentation module, or block **178**, receives the luminance image data for the selected sample area, via module **152**, and provides for segmenting the luminance image data into light and dark regimes and performing enhancement operations separately (i.e., luminance redistribution) on each of the regimes. Stated another way, the image segmentation module **178** assigns each pixel in the selected sample area to either the light or dark regime based on each pixel's relationship to the brightness midpoint value received from the midpoint calculation module **176**. Pixels with a brightness value greater than the midpoint are assigned to the light regime, and pixels with a brightness value less than the midpoint value are assigned to the dark regime.

[0091] Pixel values assigned by the image segmentation module **178** are received by the lookup table construction modules, wherein lookup tables are constructed and forwarded to the enhanced luminance image generation module **156** for remapping of the conditioned luminance signal **53**.

[0092] According to broad aspects of the invention, contrast enhancement is provided by heuristic and algorithmic

techniques, including the calculation of the image grey-level histogram and sample cumulative distribution function. Preferably, maximum utilization of available grey-levels for representation of image detail is provided.

[0093] Entropy is a measure of the information content of the image. Entropy is generally the average number of bits required to represent a pixel of the image. Accordingly, a completely saturated image with only black and white can be represented by one-bit per pixel, on and off, thus, the image entropy is one-bit. A one bit image contains less information than an eight-bit image with 256 shades of grey.

[0094] According to broad aspects of the invention, optimized entropy is provided while maintaining a monotonic grey-level relationship wherein "monotonic" generally means that the precedence order of the input grey-levels are not changed by the desired grey-level transformation employed.

[0095] In one embodiment, contrast enhancement includes calculation of the sample cumulative distribution function of the image grey-levels. The inverted sample cumulative distribution is applied to map the input grey-levels. Because the inverted sample cumulative distribution function is used, the resulting transform approximates uniformly distributed grey levels within the input range. The uniform density histogram generally has the maximum entropy.

[0096] As known by those having skill in the art, classical "histogram equalization" directly applies the inverted sample cumulative distribution function to form the grey-level mapping lookup table. In an embodiment in accordance with the present invention, along with the inverted sample cumulative distribution data, it is preferred to combine a linear mapping to ensure full-range output, and also combine a saturation bias identification to improve grey-level uniformity in the presence of saturation. As will be appreciated by those having skill in the art, image saturation creates a pathology in the inverted sample cumulative distribution mapping that is not addressed in classical histogram equalization.

[0097] When the image is saturated the histogram has a pathology—an inordinate number of pixels are black or white or both. Direct calculation of the sample cumulative distribution function produces large gaps in endpoints of the grey-level transform. Such gaps mean that the maximum number of grey-level values are not being used, and the resulting output distribution does not closely approximate the desired uniform distribution. Moreover, the resulting image will contain broad areas of a single grey-level (for both black and with saturation). Sometimes, such areas are referred to as "puddles."

[0098] An embodiment of another broad aspect of the invention is disclosed in FIGS. **8** and **9** which are simplified functional block diagrams. The contrast enhancement block diagrams of FIGS. **8** and **9** include: an identity lookup table builder **211**, a global equalized lookup table builder **213**, a plurality of zone equalized lookup table builders **215**, **217**, **219** and **221**; a plurality of non-linear transform blocks **223**, **225**, **227**, **229** and **231**; a global weight functional block **233**; a plurality of zone weighting functional blocks **235**, **237**, **239** and **241**; and a plurality of functional operators including adders, multipliers, and dividers.

[0099] The identity lookup table builder **211** constructs an identity lookup table for the image frame received. Thus, for each pixel having a contrast k, the lookup table output provided by block **211** provides the same contrast, k.

[0100] The global equalized lookup table builder **213** constructs a global equalized lookup table for the image data received. In particular, the functionality of the builder **213** within FIG. **8** is like that of block **54** within FIG. **6**. Accordingly, a range of useful grey-levels is identified. As described above, the range can include all grey-levels within a cumulative distribution function or any lesser or greater amount as desired, for example all grey levels except for the first and/or last unsaturated grey-level within the distribution function. The range is then scaled to include an extended range of grey-levels including, but not limited to, the full range of grey-levels. The builder **213** provides, as an output, the scaled range as a lookup table to the non-linear transform **223**.

[0101] Similar to the global equalized lookup table builder **213**, each of the zone equalized lookup table builders **215**, **217**, **219** and **221**, constructs an equalized lookup table for that portion of the image data within the particular table builder's zone. In particular, within each zone, a range of useful grey-levels is identified by the builder assigned to the zone. The range for each zone can include all grey-levels within a cumulative distribution function, except the first and/or last unsaturated grey-level within the zone's distribution function, or the like. The range is then scaled to include an extended range of grey-levels including, but not limited to, the full range of grey-levels. The lookup table builder for each zone then provides, as an output, its scaled range as a lookup table to a non-linear transform **223**, **225**, **227**, **229** and **231**.

[0102] FIG. **8** discloses schematically, that the non-linear transforms **223**, **225**, **227**, **229** and **231**, provide for weighting grey-level values towards white, thus brightening the image. In an embodiment, the non-linear transforms are a power function wherein the input to the non-linear transform for each pixel is normalized over the range of grey level values. For example, if there are 256 grey-level values available for each pixel, then the input for each pixel is normalized for 256 grey-level values. Then, a power is applied wherein the power is preferably a real number in the range of about 0 to about 1, and preferably 8. Therefore, the output of each non-linear transform **223**, **225**, **227**, **229** and **231**, is a lookup table (no reference number) where the values are skewed towards brightening the image.

[0103] The output of each non-linear transform **221-231** is multiplied by a weight as shown by blocks **233-241** of FIG. **8**. Accordingly, the weighting provided by global weight **233** determines the balance between combining together two or more inputs. In particular, the global weight determines the balance between the identity lookup table and the transformed global equalized lookup table. The combination or blending together of the identity lookup table **211** and the transformed global equalized lookup table **213** results in a contrast enhanced global lookup table **243**.

[0104] Likewise, the weighting provided by weights **235-241** determines the balance between the contrast enhanced global lookup table **243** and each transformed zone equalized lookup table. These combinations or blends result in a plurality of zonal balanced lookup tables **245-251** wherein the balanced lookup tables are contrast enhanced and relate, in part, to a particular zone of the original input image.

[0105] Turning to FIG. **9**, the outputs from the zonal balanced lookup tables **245**, **247**, **249** and **251** of FIG. **8**, are combined with corresponding pixel position weights for determining relative zonal pixel grey-levels **253**, **255**, **257** and **259**. The relative zonal pixel grey-levels **253**, **255**, **257** and **259**, are summed together to provide a final or composite enhanced pixel grey-level value **261** for each pixel.

[0106] In particular, the image data input provided to each lookup table **245**, **247**, **249** and **251** includes the original grey-level for each pixel within the image frame. Stated another way, each lookup table **245**, **247**, **249** and **251** receives the original grey-level image data input for each pixel within the image frame.

[0107] The outputs **263**, **265**, **267** and **269** of the lookup tables **245**, **247**, **249** and **251** provide new grey-level values for each pixel within the corresponding zone. This new grey-level values can be increased, decrease, or the same as the original luminance.

[0108] The outputs **263**, **265**, **267** and **269**, of the lookup tables are multiplied by a corresponding position weighting factor **271**, **273**, **275** and **277**. In particular, the new grey-level values for each pixel is multiplied by a weighting factor **271**, **273**, **275** and **277**, based upon the pixel's location relative to one or more reference positions within the image frame. As will be appreciated by those having ordinary skill in the art, the weighting factors **271**, **273**, **275** and **277**, govern how the grey-level within each zone effects the new grey-level values provided for each pixel within the image. Preferably, a pixel is effected more by pixel values within the zone within which it is located, and is effected less dramatically by pixel values from a zone furthest from the pixel. The weightings can be normalized so their total sum is 1.

[0109] In one embodiment, the reference positions within the image frame are located at the corners of the image frame. In a further embodiment, the reference positions can be at the centers of the defined zones.

[0110] The weightings are based upon the distance the pixel is located from the reference positions. For example, if the image frame is a square containing four equally sized zones with the reference positions at the corners of the image frame, then the weighting factors **271**, **273**, **275** and **277**, for the center pixel within the image frame would be 0.25 because the pixel is equal distant from each zone's reference position (i.e., the corners of the image frame). Likewise, each pixel at the corners of the image frame would be weighted such that only the lookup table results for the zone containing the pixel would be applied in determining the pixel's new grey-level.

[0111] In yet another embodiment, and as will be appreciated by those having ordinary skill in the art, only a single zone can be used within an image frame. Preferably, the zone is centered in the image frame and is small in size than the entire image frame.

[0112] It should be understood that the device **10** and its combination of elements, and derivatives thereof, provide circuits and implement techniques that are highly efficient to implementation yet work very well. Others have proposed various forms of contrast enhancement solutions but the proposals are much more complex to implement. Apparatus and methods according to the invention create an algorithmically efficient procedure that results in cost efficient real-time implementation. This, in turn provides lower product costs.

[0113] While the specific embodiments have been illustrated and described, numerous modifications come to mind without significantly departing from the spirit of the invention and the scope of protection is only limited by the scope of the accompanying claims.

1. A device providing an image output frame in response to an image input frame, the device comprising: a housing having a printed circuit board contained therein; an input connector attached to the housing and having a conductive path attached to the printed circuit board; an output connector attached to the housing and having a conductive path attached to the printed circuit board; an integrated circuit placed on the printed circuit board, the integrated circuit having an output responsive to the image input frame, the output comprising transformed pixel frame data; and wherein the device does not require a keyboard to operate.

2. The device of claim 1 wherein the device is an embedded system.

3. The device of claim 1 wherein the input connector receives thirty frames per second and the output connector provides thirty frames per second.

4. The device of claim 1 wherein a port is not provided for operably attaching the device to the keyboard.

5. The device of claim 1, further comprising a saturation bias identification circuit having a range of useful grey-levels output responsive to the image input frame, and a cumulative distribution function scaling circuit having a scaled output responsive to the useful grey-levels output.

6. A method for providing an image output frame in response to an image input frame, the method comprising the steps of: segmenting the image input frame into one or more zones; determining a plurality of grey-level values for a pixel based, at least in part, on grey-level data contained within the one or more zones; and, calculating a composite enhanced pixel grey-level value for the pixel by blending the plurality of grey-level values.

7. The method of claim 6 wherein the image input frame is segmented into a plurality of zones.

8. The method of claim 6 further comprising establishing reference points within the image input frame, and wherein the step of calculating a composite enhanced pixel grey-level value is based, at least in part, on distance from the reference points.

9. The method of claim 6 further comprising the step of generating a digital output responsive to the image input frame.

10. The method of claim 6 further comprising the step of generating an analog output in response to the image input frame.

11. The method of claim 6 further comprising the step of generating a luminance output signal in response to the image input frame.

12. The method of claim 6 further comprising the step of generating a conditioned output responsive to the image input frame.

13. A method for providing an image output frame in response to an image input frame, the method comprising the steps of: establishing reference points within the image input frame; calculating grey-level values for a plurality of pixels within the image input frame; and, calculating a

composite enhanced pixel grey-level value for the pixels based, at least in part, on distance from the reference points.

14. The method of claim 13 further comprising segmenting the image input frame into a plurality of zones, and wherein at least one of the reference points is located within one of the zones.

15. The method of claim 13 further comprising generating a range of useful grey-levels in response to the image input frame, and generating a scaled output in response to the range of useful grey-levels.

16. A method for providing an image output frame in response to an image input frame, the method comprising the steps of: constructing an equalized lookup table for the image input frame; constructing an equalized lookup table for a zone within the image input frame; and, utilizing the lookup tables to build a balanced lookup table.

17. The method of claim 16 further comprising the step of utilizing a lookup table representative of the image input frame to build the balanced lookup table.

18. A method for providing an output of signal values in response to an input array of signal values derived directly or indirectly from a sensor, wherein each input value is variable within a range of values based upon an environment sensed by the sensor, and each value of the input signal has coordinates with a spatial and or geometric relationship to other values in the input signal, comprising the steps of: segmenting the image input array into one or more spatial zones; determining a plurality of signal intensity values for a coordinate based, at least in part, on signal intensity contained at coordinates within the one or more other zones; and, calculating a composite enhanced coordinate signal value for the coordinate by blending the plurality of signal intensity values.

19. A method for providing an output of signal values in response to an input array of signal values derived directly or indirectly from a sensor, wherein each input value is variable within a range of values based upon an environment sensed by the sensor, and each value of the input signal has coordinates with a spatial and or geometric relationship to other values in the input signal, comprising the steps of: establishing reference points within the array of signal values; calculating signal intensity values for a plurality of coordinates within the array of input values; and, calculating a composite enhanced coordinate signal intensity value for the coordinates based, at least in part, on a distance of the coordinate from the reference points.

20. A method providing an output of signal values in response to an input array of signal values derived directly or indirectly from a sensor, wherein each input value is variable within a range of values based upon an environment sensed by the sensor, and each value of the input signal has coordinates with a spatial and or geometric relationship to other values in the input signal, comprising the steps of: constructing an equalized lookup table for the array of signal intensity values; constructing an equalized lookup table for a zone within the array of signal intensity values; and, utilizing the lookup tables to build a balanced lookup table.

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