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(54) IMAGE SENSOR BASED VIGNETTING CORRECTION

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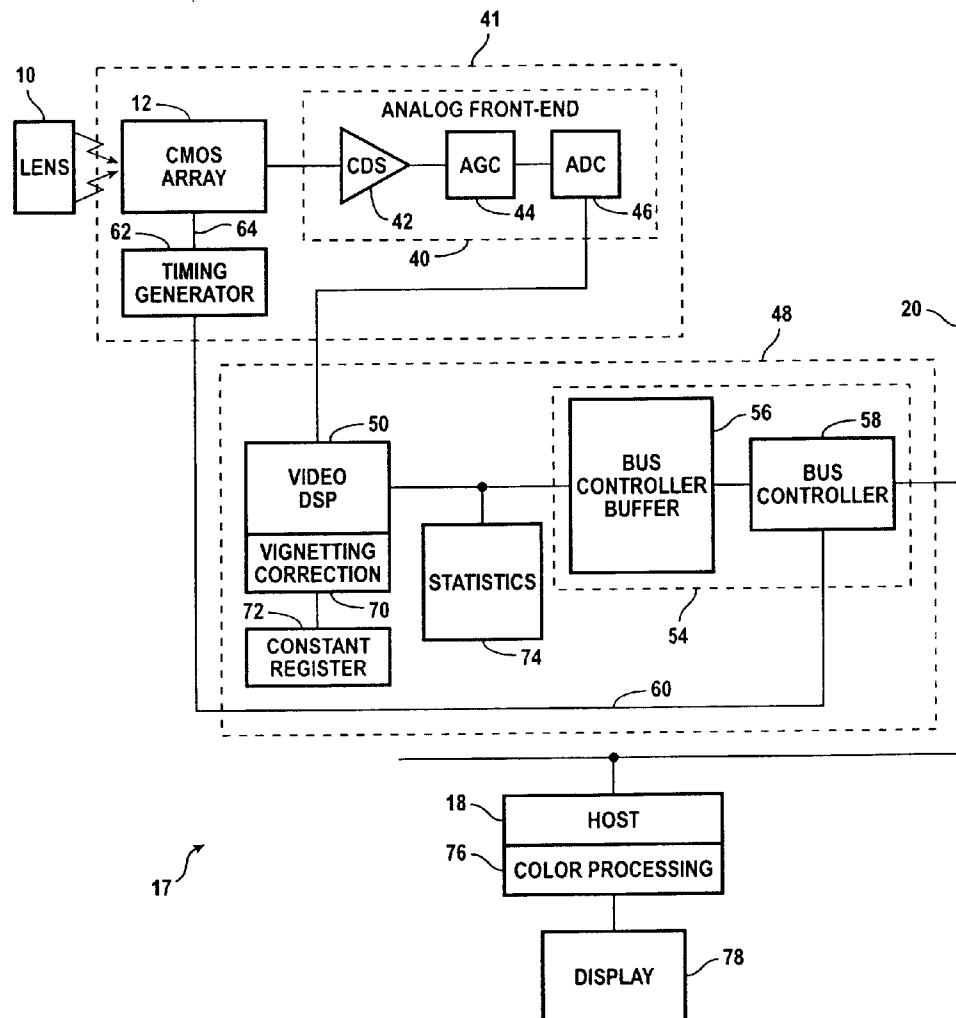
(63) Continuation of application No. 10/282,734, filed on Oct. 28, 2002, which is a continuation-in-part of application No. 09/345,167, filed on Jun. 30, 1999, now Pat. No. 6,833,862.

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(57) ABSTRACT

A method and apparatus for constructing an inexpensive camera with vignetting correction in the camera electronic hardware. The hardware is programmable through the use of a register storing a constant value corresponding to the amount of vignetting of a particular lens used in the camera. The register value is provided to a correction circuit which implements an algorithm that corrects for the amount of vignetting of pixels depending upon the pixel position.



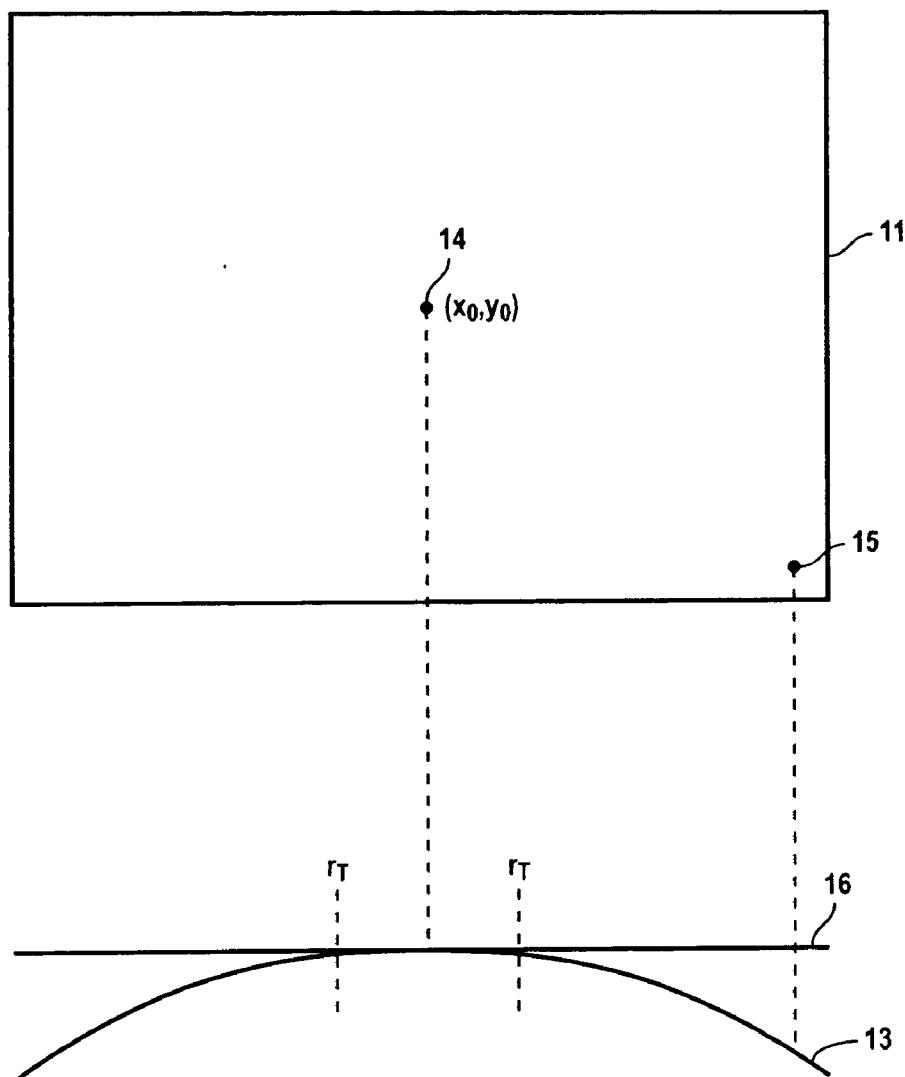


FIG. 1

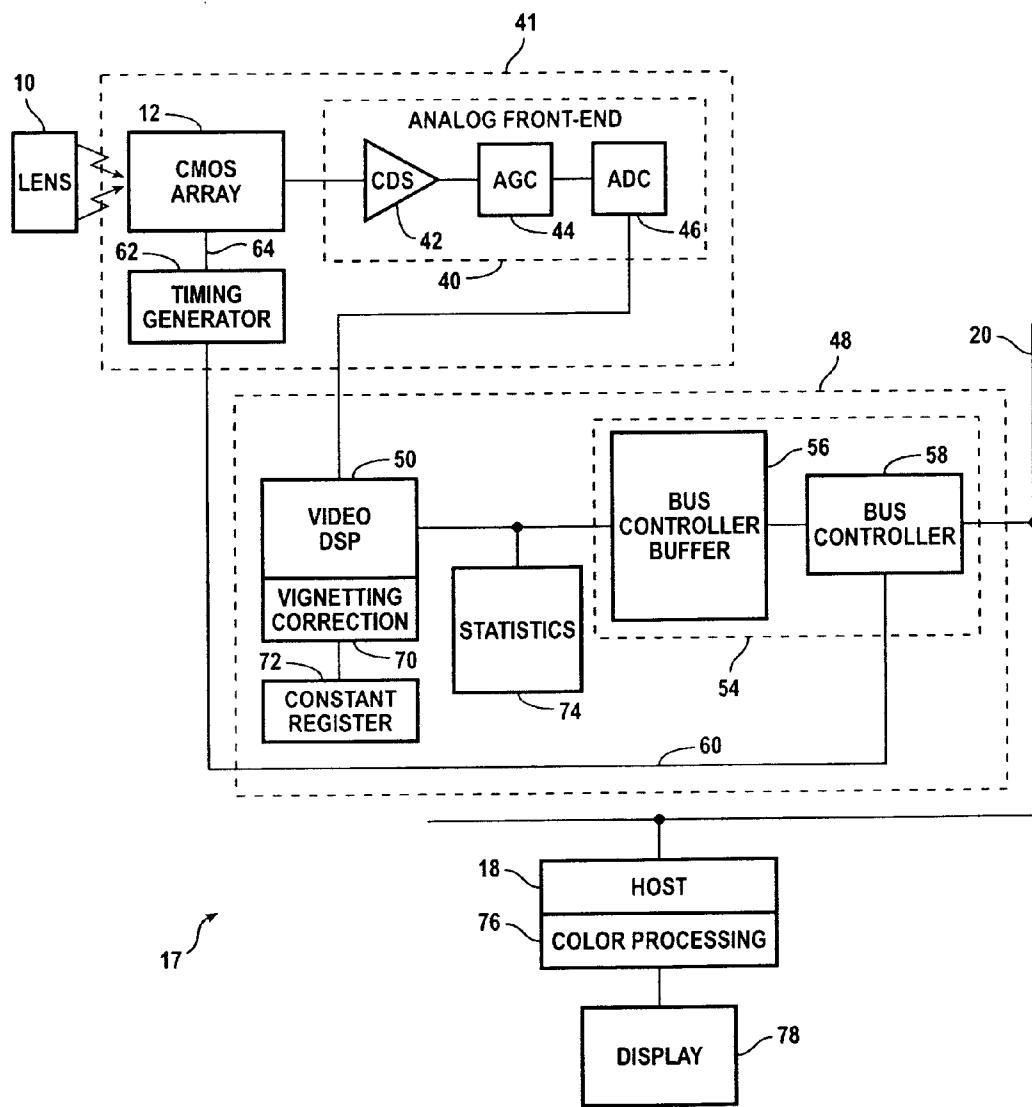


FIG. 2

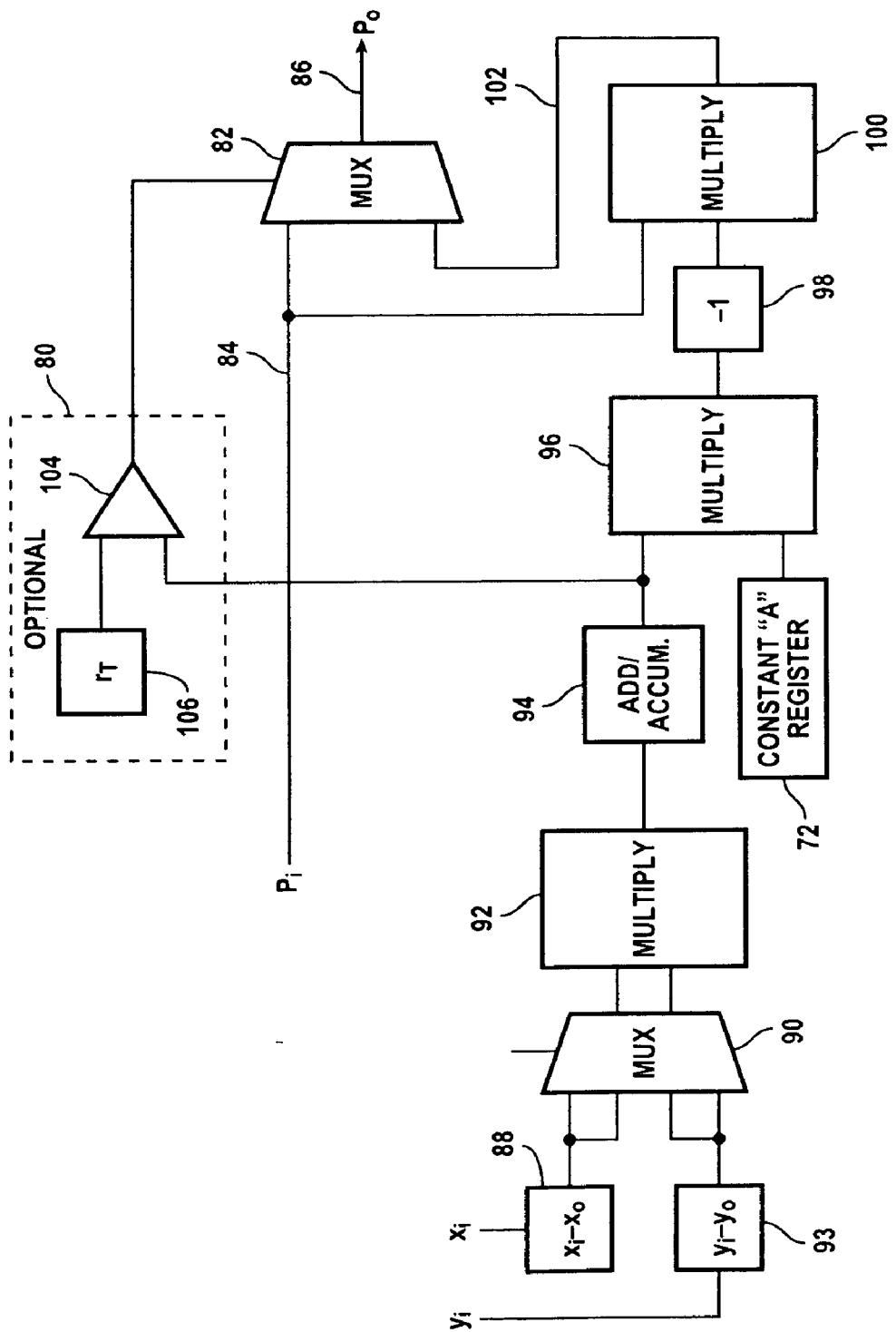


FIG. 3

IMAGE SENSOR BASED VIGNETTING CORRECTION

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application is a Continuation Application of U.S. patent application Ser. No. 10/282,734, filed Oct. 28, 2002 and titled "Image Sensor Based Optical Defect Correction," and is a Continuation Application of U.S. patent application Ser. No. 09/345,167, filed Jun. 30, 1999 and titled "Image Sensor Based Vignetting Correction," both of which are incorporated by reference herein in their entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to digital cameras, and in particular to correcting vignetting effects.

[0003] The vignetting effect is when the brightness around the edges of a screen is less than the brightness in the center of the screen, creating a halo effect. Professional photographers will sometimes try to intentionally create this effect with an appropriate lens or screen, to produce a softened image at the edges of a picture. However, when this effect appears unintentionally in digital photographs, it is annoying. A variety of techniques have been developed to measure and address vignetting effects.

[0004] U.S. Pat. No. 4,884,140 shows an analog circuit for providing vignetting compensation for a video camera using a zoom lens which causes vignetting.

[0005] U.S. Pat. No. 5,434,904 shows measuring the vignetting effect for an x-ray examination apparatus by using a constant brightness image. A correction factor is then stored in the memory for each pixel.

[0006] U.S. Pat. No. 5,576,797 shows the detection of vignetting effects in a camera with a focus detecting device.

[0007] U.S. Pat. No. 5,381,174 shows the correcting of vignetting due to operation of a zoom lens by using a field frequency sawtooth signal.

[0008] U.S. Pat. No. 4,816,663 shows the detection of vignetting between a photo taking lens and focus detecting optical system.

[0009] Digital cameras for use with a personal computer for personal teleconferencing have become cheaper and cheaper. This puts pressure on the camera manufacturers to use cheaper lenses, which have more of a vignetting effect. In addition, the price pressure forces manufacturers to use fewer semiconductor chips, thus making the use of semiconductor memory to store vignetting corrections undesirable. Accordingly, there is a need for a digital camera which is inexpensive to manufacture and also corrects for vignetting of an inexpensive lens.

SUMMARY OF THE INVENTION

[0010] The present invention provides a method and apparatus for constructing an inexpensive camera with vignetting correction in the camera electronic hardware. The hardware is programmable through the use of a register storing a constant value corresponding to the amount vignetting of a particular lens used in the camera. The register value is

provided to a hardware correction circuit which implements an algorithm which corrects for the amount of vignetting of pixels depending upon the pixel position.

[0011] The invention thus allows different lens suppliers or lens types to be used in cameras as they are manufactured, by simply programming a different computed value into the register. The correction is applied on the raw sensor data after it is converted into digital form, near the sensor itself. Thus, the data is corrected prior to the optional collection of statistics on the sensor data and the compression of the data for transmission to a host computer over a bus. The vignetting correction of the invention maintains the resolution of the image and allows real-time performance. It also makes more accurate statistics collection, thus making the automatic gain control (AGC) in the host, and the automatic white balance (AWB) in the host more accurate.

[0012] For a further understanding of the nature and advantages of the invention, reference should be made to the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a drawing of a pixel array and brightness curve illustrating the vignetting effect.

[0014] FIG. 2 is a block diagram of a camera and computer system with vignetting correction according to one embodiment of the invention.

[0015] FIG. 3 is a block diagram of one embodiment of a hardware vignetting correction circuit according to the invention.

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

[0016] FIG. 1 illustrates a pixel array 11 and a corresponding brightness curve 13 over the Y axis. A central pixel 14 with value (x_0, y_0) corresponds to the point of maximum brightness of the lens. A second example pixel 15 is near the minimum brightness, showing a vignetting effect of having the difference between curve 13 and a maximum brightness value 16. The present invention corrects this vignetting effect in both X and Y directions.

[0017] In one embodiment, a threshold indicated by r_T is illustrated within which the curve 13 is near the maximum value 16, and no vignetting correction need be applied. Alternately, the correction can be applied to all of the pixels regardless to avoid any transition effects at the points r_T .

[0018] FIG. 2 illustrates a camera and computer system implementing the vignetting correction of the invention. Shown is a video camera 17 and host computer 18. Video camera 17 includes a lens 10 and a photo sensor array, such as a CMOS or CCD array 12, and is connected to a USB (Universal Serial Bus) 20.

[0019] The signals from the CMOS chip are provided to an analog front end 40 which includes a differential amplifier or correlated double sampler (CDS) 42, which provides the analog signals to an automatic gain control (AGC) circuit 44. The data is then provided to an analog-to-digital converter (ADC) 46.

[0020] The digitized signals, rather than being stored in a frame buffer memory as in the prior art, are then provided

directly to a digital processing circuit **48**. They are first provided to a video digital signal processor **50** which performs the compression, cropping, scaling and other functions on the data, as well as digital filtering.

[0021] Data from video DSP **50** is provided to a bus interface **54** which includes a bus controller buffer **56** and a bus controller **58**. Preferably, bus controller buffer **56** is capable of storing two USB frames at the maximum possible rate, or 2 Kbytes. Depending upon the frame rate, compression rate, etc., this may typically vary up to **10** lines, or even to 15-20 lines if decimation is done.

[0022] Bus controller **58** provides a control signal on a line **60** to a timing generator **62**. Timing generator **62** provides clocking signals on line **64** to CMOS chip **12**. Clocking signals **64** include the horizontal and vertical transfer pulses. In one embodiment, the analog front end **40** and the timing generator **62** are integrated onto the same semiconductor chip substrate **41** as CMOS array **12**.

[0023] DSP unit **50** includes a vignetting correction circuit **70** according to the present invention. This circuit utilizes a constant value in a constant register **72** to perform the vignetting correction. Depending upon the particular lens **10** which is chosen, its specified vignetting amount can be used to provide constant **72**. Thus, different lenses could be used in manufacturing a camera by simply programming a different constant value into register **72**. This allows multiple sources to be used for the lenses, and allows compensation for changes in lens quality from lot to lot or manufacturer to manufacturer.

[0024] As can be seen, the vignetting correction is done before a statistics unit **74** collects statistics which are then transmitted to the host processor **18**. In addition, it is prior to any compression performed in bus interface **54**.

[0025] On the host side of bus **20**, host **18** includes a color processing unit **76** which can perform AGC and AWB (automatic white balance) adjustments based on the statistics provided it. Since the vignetting correction is applied before the statistics are taken, this processing will be more accurate. In addition, the application of the vignetting correction prior to compression and transmission over the bus also improves the accuracy of the signal. After color processing, the signal is provided to a display **78** as shown.

[0026] An embodiment of an equation for implementation and hardware to perform the vignetting correction is set forth below. The vignetting defect of a low quality lens may be modeled as pass through in the middle of the lens and a parabolic curve near the edge of the lens. The transform function is isotropic. Let p_i and p_o be the pixel value before and after vignetting correction, and x_0 and y_0 be the coordinate of the center of the lens (should be the center of the image if the lens is mounted properly). Then,

$$\begin{aligned} p_o &= p_i * (a * r^2 + 1) \\ &= p_i * (a * ((x - x_0)^2 + (y - y_0)^2) + 1 \end{aligned}$$

[0027] "a" is a small positive constant. To be on the safe side, a maximum of 50% vignetting can be corrected, which means:

$$1.0 = 0.5 * (a * (176 * 176 + 144 * 144) + 1)$$

$$a = 1.9338 * 10^{-5}$$

[0028] Normalized by 2^{26} , this will give $a = 1298$. By limiting a to 0 through 1023, and performing the inverse computation, the maximum correctable vignetting is 56%.

[0029] Note that in the formula given above, the pixel aspect ratio is not taken into account. For square pixel, the equation is exact, for 12/11 pixel aspect ratio, the result is slightly off. Also, a will be scaled by $1/4$ if the sensor format is non-scaled QCIF (subsampled QCIF from CIF by leaving out every other pixels in both horizontal and vertical directions).

[0030] If y_i is 10 bits, $(x - x_0)^2$ and $(y - y_0)^2$ is 16 bits (for CIF size), and y_0 is 10 bits, this determines that a needs to be 10 bit (0 through 1023).

[0031] **FIG. 3** is a block diagram of one embodiment of a hardware system for implementing the equation described above. In particular, an optional selection circuit **80** is applied to the select input of a multiplexer **82**. Where the pixel position is less than the threshold r_2 , the input pixel p_i on line **84** is simply passed through to the output pixel, p_o , on line **86**. If it is greater than the threshold, a vignetting correction is applied by implementing the formula above with the hardware shown in **FIG. 3**.

[0032] In particular, the current x value of the pixel, x_i , is applied to arithmetic circuit **88**, where the central pixel, x_0 , is subtracted from it. This value is then squared by applying its input twice, through a multiplexer **90**, to a multiply circuit **92**, where it is accumulated in an add/accumulator **94**. Similarly, the y value y_i is provided to a circuit **9693**, where the difference from the center y value, y_0 , is determined. This is similarly applied as two values through mux **90** to a multiplier **92**, where it is squared and provided to add/accumulator **94**, where it is added to the squared x value. The use of the multiplexer simply allows, by time division multiplexing, the same multiplier **92** to be used for both calculations. Obviously, an alternative would be to provide two separate multiply units.

[0033] The output of accumulator **94** is then provided to a second multiplier **96**, where it is multiplied by the constant value from register **72**. The value of one is then subtracted in a unit **98**, and this value is multiplied by the pixel value, p_i , in a multiplier **100**. The output is provided on a line **102** through multiplexer **82** to output line **86**. Obviously, variations of the circuitry could be provided, such as using the same multiply circuit for multipliers **92**, **96** and **100**, with the multiplier being used for different purposes in different time slots.

[0034] Optional circuit **80** provides a comparator **104** which compares the output of add/accumulator **94** (the radius value of the $x^2 + y^2$ values) to the threshold radius in a register **106**.

[0035] Preferably, the constant a has the same number of bits as the pixel value, p_i . Thus, if p_i is 10 bits, while the x and y values are 16 bits, the constant a would be 10 bits. Also, a can be scaled by $1/4$ if the sensor format is non-scaled QCIF (cropped). Thus, correction is provided where the image is cropped before the vignetting correction.

[0036] In addition, correction can be done for the pixel aspect ratio by multiplying the y value by 11/12 where a TV will be used.

[0037] In one embodiment, the correction will take place only outside a predefined diameter. This assumes that the lens performs satisfactorily around the center of the lens, which is often a reasonable assumption. By doing so, a more accurate correction model can be derived. Let r_T be the diameter within which the vignetting defect can be ignored. Then,

If $r \leq r_T$,
 $p_o = p_i$,
 if $r \geq r_T$,

[0038]

$$\begin{aligned} p_o &= p_i * (a * (r^2 - r_T^2) + 1) \\ &= p_i^* (a * (((x - x_0)^2 + (y - y_0)^2) - ((x_T - x_0)^2 + (y_T - y_0)^2)) + 1) \end{aligned}$$

[0039] The present invention thus allows variation in lenses and also cheaper lenses to be used. It improves the AGC and AWB in the host computer. Additionally, it allows better object motion tracking. Object motion is usually done by assuming the luminance value is the same as the object moves to the edge of a sensor, and thus tracking by looking for the same luminance value. Obviously, vignetting effects can thwart the efforts to locate the object. By applying the vignetting correction close to the sensor, this can be overcome. The invention also provides overall improved video quality.

[0040] Also, due to the need for image compression for transmitting over a bus, such as a universal serial bus (USB), having the host do vignetting corrections will result in less precision. Providing vignetting correction on the sensor side of the bus in the present invention provides the correction prior to compression to transmit over the bus.

[0041] As will be understood by those of skill in the art, the present invention may be embodied in other specific forms without departing from the essential characteristics thereof. Accordingly, the foregoing description is intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

What is claimed is:

1. A method for manufacturing a camera which connects to a computer, comprising:
 - determining a vignetting effect of a first lens;
 - installing said first lens in a first camera housing;
 - determining a vignetting effect of a second lens;
 - installing said second lens in a second camera housing;
 - installing in each housing a photosensor array mounted behind said lens;
 - coupling an analog processing circuit to each said photosensor array;
 - coupling an analog to digital converter to each said analog processing circuit;
 - coupling a digital processing circuit to an output of each said analog to digital converter, said digital processing circuit including
 - a register for storing a constant corresponding to a vignetting rating of said lens,
 - a correction circuit, coupled to said register, for adjusting a value of selected pixels according to a formula using said constant, to correct for vignetting of said lens;
 - coupling a bus interface circuit to an output of each said digital processing circuit for connecting to a bus for transfer of data to said computer;
 - storing a first constant in said register in said first camera housing, said first constant corresponding to said vignetting effect of said first lens;
 - storing a second constant in said register in said second camera housing, said second constant corresponding to said vignetting effect of said second lens.
2. The method of claim 1 wherein said correction circuit does not adjust the value of pixels within a selected distance of a center of said lens.
 3. The method of claim 1 wherein said correction circuit also corrects for a pixel aspect ratio.
 4. The method of claim 1 wherein said constant has a number of bits equal to a number of bits used to represent a brightness of said selected pixels.
 5. The method of claim 1 wherein said correction circuit further comprises a scaling input for scaling said constant.
 6. A camera for connecting to a computer, comprising:
 - a lens;
 - a photosensor array mounted behind said lens;
 - an analog processing circuit coupled to said photosensor array;
 - an analog to digital converter coupled to said analog processing circuit;
 - a digital processing circuit coupled to an output of said analog to digital converter, said digital processing circuit including
 - a register for storing a constant corresponding to a vignetting rating of said lens,
 - a correction circuit, coupled to said register, for adjusting a value of selected pixels according to a formula using said constant, to correct for vignetting of said lens; and
 - a bus interface circuit coupled to an output of said digital processing circuit for connecting to a bus for transfer of data to said computer.
 7. The camera of claim 6 wherein said correction circuit does not adjust the value of pixels within a selected distance of a center of said lens.
 8. The camera of claim 6 wherein said correction circuit also corrects for a pixel aspect ratio.
 9. The camera of claim 6 wherein said constant has a number of bits equal to a number of bits used to represent a brightness of said selected pixels.
 10. The camera of claim 6 further comprising a scaling input to said correction circuit, for scaling said constant.