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(54) Method of Digital Image Enhancement

(57) Abstract

The present invention relates to a method of digital image enhancement and comprises a step of converting from an RGB color space to the luminance channel of an image, a step of filtering the luminance channel of the image by a bilateral filter, a step of correcting shadow to increase local contrast and luminance, respectively, and correcting highlight to increase local contrast and decrease luminance at the luminance channel of the image, and a step of converting the corrected image into an RGB color space. By this, the quality of photographs can be improved while being printed on a photo printer.

Representative drawing

FIG. 3

Scope of Claims

Claim 1.

A method of digital image enhancement, comprising:

a step of converting from an RGB color space to the luminance channel of an image;

a step of filtering the luminance channel of the image by a bilateral filter;

a step of correcting shadow to increase local contrast and luminance, respectively, and correcting highlight to increase local contrast and decrease luminance at the luminance channel of the image; and

a step of converting the corrected image into an RGB color space.

Claim 2

The method of digital image enhancement of Claim 1,

wherein the bilateral filter is used for noise suppression.

Claim 3.

The method of digital image enhancement of Claim 1,

wherein the bilateral filter is characterized by the application of a general function to the space kernel.

Claim 4.

The method of digital image enhancement of Claim 1,

wherein the bilateral filter is applied to a range of filtering the following formula:

$$w(x) = \frac{1}{\sqrt{1 + \left| \frac{x}{\sigma_R^2} \right|^\mu}}$$

Claim 5.

The method of digital image enhancement of Claim 1,

wherein the bilateral filter processes the image using the following formula first by row and then by column:

$$I_f^*(r, c) = \frac{\sum_{j=-S/2}^{S/2} I(r, c+j) * w(I(r, c+j) - I(r, c))}{S * \sum_{j=-S/2}^{S/2} w(I(r, c+j) - I(r, c))}$$

$$I_f(r, c) = \frac{\sum_{i=-S/2}^{S/2} I_f^*(r+i, c) * w(I_f^*(r+i, c) - I_f^*(r, c))}{S * \sum_{i=-S/2}^{S/2} w(I_f^*(r+i, c) - I_f^*(r, c))}$$

Claim 6.

The method of digital image enhancement of Claim 1,

wherein at the step of correcting the shadow, a difference between the reflection estimate for the shadow tone and the luminance is added to the luminance channel of the image, and the difference is multiplied by the bilateral filtering result of the negative that is increased to a power defining the next corrected tone range and multiplied by the shadow amplification rate.

Claim 7.

The method of digital image enhancement of Claim 6,

wherein the reflectance estimate for the shadow tone is expressed as a function of the ratio of the source image to the filtered image.

Claim 8.

The method of digital image enhancement of Claim 6,

wherein the reflectance estimate for the shadow is calculated by the following formula:

$$D_s(r, c) = \frac{1.3 * I(r, c)}{I_f(r, c) + 3 * \sigma_R}$$

Claim 9.

The method of digital image enhancement of Claim 1,

wherein at the step of correcting the highlight, the difference between the reflectance estimate and the luminance for the highlight tone is deducted from the luminance channel, the difference is multiplied by the bilateral filtering result that is increased to a power defining the tone range to be corrected next and then multiplied by the highlight attenuation rate.

Claim 10.

The method of digital image enhancement of Claim 9,

wherein the reflectance estimate for the highlight tone is expressed as a function of the ratio of the filtered image to the source image luminance.

Claim 11.

The method of digital image enhancement of Claim 9,

wherein the reflectance estimate for the highlight tone is calculated by the following formula:

$$D_h(r, c) = \frac{3 * \sigma_R * I_f(r, c)}{1.3 - I(r, c)}$$

Claim 12.

The method of digital image enhancement of Claim 1,

wherein the following formula is used to convert the corrected image into an RGB color space:

$$R' = R * I_d, \quad G' = G * I_d, \quad B' = B * I_d,$$

Claim 13.

The method of digital image enhancement of Claim 1,

wherein at the above correction step, a 2D lookup table is calculated to shorten processing time, and the table stores the value that is corrected according to the bilateral filtering results and the luminance.

Specifications**Detailed Description of the Invention****Purpose of the Invention****Technology to which the invention belongs and the prior art in that field**

The present invention relates generally to the field of digital imaging technology. In particular, it relates to the field of methods for improving digital cameras and grayscale photographs, and more specifically to global (overall) and local tone adjustment of shadow and highlight correction, noise suppression and sharpening.

There are numerous patents and publications on digital image enhancement. Most methods involve tone adjustment, noise suppression, and shadows. What is intended to be basically improved in the present invention is a method of correcting shadows and highlights.

Massive consumer photographs taken with digital cameras, such as those affected by backlit defects, have a low dynamic range in the shadow area.

The low dynamic range in the highlights is rarely encountered in case of photos taken with DSC, but scanned photos have such characteristics. There are many patents and publications that belong to the local tone correction, mainly shadow tones.

Intuitively clear and simple methods of shadow and highlight correction are disclosed in the U.S. Patent No. 6822762, "Local Color Using Nonlinear Masking" of Moroney et al. (2004) and N. Moroney [8th Color Imaging Conference of 2000]. The mask is generated as a result of the strong blurring of the luminance channel. In case of such blurring, a linear low pass filter (LPF) is applied. In addition, each RGB component is converted using tone reproduction curve groups whose curve shape depends on the mask value. For example, an image formulated in range [0,1] represents the following formula:

$$R = (R)^{2^{(1-2\text{Mask})}}; \quad G = (G)^{2^{(1-2\text{Mask})}}; \quad B = (B)^{2^{(1-2\text{Mask})}}$$

Similar methods are disclosed in the U.S. Patent No. 6792160 (2004) of Shaw et al. Similar techniques are used for the correction of shadows in software packages, such as the "Shadow/Highlight" menu item of Adobe Photoshop CS.

The basic weakness of the given methods lies with the formation of a halo-effect. In addition, the noise level in the shadow tone is increased.

International application WO 02/089060 (2002) of Chesnokov discloses an image enhancement method based on Orthogonal Retino-Morphic Image Transform (ORMIT).

$$I = \sum_{i=0}^N a_i(I) * LPF(P_i(F(I))) * Q_i(F(I)) + b(I)$$

In the above formula, $P_i(x)$ is an orthogonal basis that is a function of x defined in $0 < x < 1$, Q_i is an anti-derivatives of P_i or an approximation thereof, LPF is an operator of a low pass spatial filter, F is a weight function similar to a gamma correction, and N is the number of bands (bands), i.e., $N \ll n$, wherein n is the color depth and a and b are specific constants of each band. The selection of a suitable P_i increases local contrast and luminance in the shadow area. The given method is used in the Nikon "D-Lighting" technology. The method forms an almost non-negligible halo, but the noise level of the shadow tone is increased.

Another common method of shadow correction employs the simplest physical model to form a grayscale image I as follows:

$$I = R * L,$$

In the above equation, L is the brightness of the subject, which changes relatively low, and R is the reflectance (or albedo) of the subject changing at a high frequency (MIT Press, 1986, B.K.P. Horn "Robot Vision").

The given model does not take into account the images of the light sources, the mirror reflections (however, diffuse Lambert reflections) and the opportunities for appearance when forming shadows from the subject.

Despite the drawbacks, the model applies very well to a wide class of images and is used in the methods described later. Reflectance in these methods is estimated by different methods, but is always estimated in the ratio of I and L .

U.S. Patent No. 6760484 of Sobol et al., Publication of 2002/0154323 of Sobol et al., 2002/0154832 of Sobol et al., 2003/0161546 of Sobol et al., and 2004/0174571 of Sobol and Sobol R. "Improving the Retinex algorithm for rendering wide dynamic range photographs" [Volume 13, Issue 1, Pages 65-74, of the January 2004 magazine, "Electronic Imaging"] discloses a method for correcting shadows based on modifications to the Multiscale Retinex (MSR) algorithm. Simply put, the idea of this method is as follows: The modified MSR is performed for the luminance channel. The luminance is calculated as $\max(R, G, B)$. The result of the modified MSR is referred to as a mask. The mask is added to R , G and B channels.

The conventional MSR is obtained by the following formula:

$$I = \sum_{n=l}^N \omega_n * (\log(I) - \log(LPF_n(I)))$$

In the above formula, LPF is Gaussian blur with various σ .

In Sobol's method, the optimal calculation algorithm is used for the realization of Gaussian blur. In addition, the set of thresholds is additionally put into the calculation algorithm. The given method is used in a technique by HP called "Adaptive Lighting." The method forms an almost non-negligible halo, but increases the noise level of the shadow tone.

In the U.S. Publication No. 2005/0089239 of Brajovic and Paper Brajovic V., "Brightness Perception, Dynamic Range and Noise: a unifying model for adaptive image sensors" [Proceedings of 2004 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, Vol. 2, pages II-189 to II-196], the method depicts a screen of high dynamic images in low dynamic range devices that include shadow correction of the following formula:

$$I = S(R + a * L),$$

In the above formula, a is an attenuation constant, S is a linear scaling operator that scales the results for the global signal range, L is a result of applying edge-preserving filtering, and R is a function of the ratio between luminance of the source image and L . Edge-preserving filtering is performed for each scanning line of the image, and the operation of the filter is based on an estimate of the noise level of the image.

Noise is suppressed in the luminance channel, but noise remains in the chromaticity channel. The advantage of this method is that there is no noticeable halo.

In the methods described above, no consideration was given to highlight correction, automatic selection of correction parameters, and joint correction of shadows/highlights, and adjustments to the global contrast of the image, i.e., posterization effects, are often possible.

Safonov's Russian Published Application No. 2005/112311 proposes a shadow correction in which global contrast adjustment and correction parameters are automatically selected. Nevertheless, the proposed method is for the correction of shadows and is not suitable for compound image enhancement that includes highlight region correction. Furthermore, this technique exhibits a distinct noise level in the dark area.

The current technology used for local dynamic correction has the following important drawbacks:

- * The highlight tone is not corrected.
- * Conventional methods do not have a combination of global contrast adjustment and shadow correction.
- * Some algorithms induce halo-effects near the contrast sharp boundaries.
- * The application of existing algorithms increases noise and/or JPEG artifacts in shadows.
- * Posterization effects are often possible.
- * Existing solutions are not suitable and correction levels cannot be obtained automatically.

Technical Challenges Invention Is Trying to Solve

The present invention is intended to solve the above problem and is intended to provide a method of image enhancement with regard to global contrast adjustment, local shadow and highlight correction, i.e. noise suppression and sharpening.

Composition of the Invention

Description of Novelty and Inventive Step

1. Images are filtered using a bilateral filter in advance to suppress noise.
2. The Applicant proposes to reduce the increase in sharpening by using a bilateral filter with a flat domain kernel and universal El-Fallah-Ford edge-stop function when correcting shadows and highlights.
3. The shadow correction is achieved by adding a difference between the reflection estimate for the shadow tone and the luminance to the luminance channel, which is multiplied by the bilateral filtering result of the negative, which is elevated to the power defining the tone range that is then corrected, and then multiplied by the shadow amplification factor. Here, the reflectance estimate for the shadow tone is a function of the ratio of the source image to the filtered image.
4. Highlight correction is achieved by cutting from the luminance channel of the difference between reflection estimates and luminance for the highlight tones, where the difference is multiplied by the bilateral filtering result that is then elevated to a power that defines the tone range to be corrected later, and then multiplied by the highlight attenuation rate. Here, the reflectance estimate for the highlight tone is a function of the ratio of filtered image to the source image luminance.
5. It is proposed to apply a bilateral filter in row-column fashion and also to define the correction function, as decimated in the 2-D lookup table.

Embodiment

FIG. 1 shows an operating diagram of the basic configuration of a system that realizes the method. The operating process of the device is controlled by a processor (101) running program codes stored in the program memory (102). The memory (102) stores source grayscale or color photos. The color image is stored in the RGB color space with the size of $N \times M$ and the color depth d (color depth for $n = d/3$ channels). If the color space of the source color image is different from the RGB, a conversion to RGB color space is required. A grayscale image has a size of $N \times M$ and a color depth of n bpp. The image is enhanced and transported to a printing device or a screen device (103). Correction parameters are entered into the system using an input device (104). The exchange of information is carried out via the data bus (105).

Let's consider the basic idea of shadow and highlight correction proposed in the present invention for grayscale photographs with luminance values ranging from 0 to 1.

Some photographs, such as those affected by backlit defects, have low dynamics in shadow and/or highlight areas. Therefore, for an observer, it causes difficulty in identifying details in shadows and highlights especially with corresponding brighter and darker contrasts than moderately exposed areas. Therefore, it is necessary to increase local contrast in the shadow and highlight areas, increase luminance within the shadow, and also decrease luminance in the highlight.

Let's take "detail image" D_s with high local contrast in shadows, and "digital image" D_h with high local contrast in the highlight area, i.e. images that can identify digital correspondingly well in shadows and highlights. It is then possible to increase the local contrast and luminance of the source image I using the following alpha blending formula of I and D_s :

$$I_{es}(r,c) = I(r,c) * \alpha_s(r,c) + (1 - \alpha_s(r,c)) * (k'_s * D_s(r,c) + (1 - k'_s) * I(r,c)) \quad (1)$$

For all pixels (r,c) of Image I , in the above formula, α_s is an alpha-channel of permeability with a value close to 1 in the bright area and a value close to 0 in the dark area, and the factor k'_s controls the amplification level of the local contrast in the shadow. After opening the parenthesis, we can get the following formula:

$$I_{es}(r,c) = I(r,c) + k'_s * (1 - \alpha_s(r,c)) * (D_s(r,c) - I(r,c)). \quad (2)$$

In the same way, it is possible to increase the local contrast of the source image I and also reduce luminance using the following alpha blending formula of I and D_h :

$$I_{eh}(r,c) = I(r,c) - k'_h * (1 - \alpha_h(r,c)) * (I(r,c) - D_h(r,c)), \quad (3)$$

In the above formula, α_h is a permeable alpha-channel having a value close to zero in the bright area and a value close to 1 in the dark area,

and the factor k'_h controls the amplification level of the local contrast in the highlight.

The results of the shadow and highlight correction can be synthesized by the following formula:

$$I_e(r, c) = (I_{es}(r, c) + I_{eh}(r, c)) / 2 = \\ = I(r, c) + k_s * (1 - \alpha_s(r, c)) * (D_s(r, c) - I(r, c)) - k_h * (1 - \alpha_h(r, c)) * (I(r, c) - D_h(r, c)), (4)$$

In the above formula, k_s is the shadow amplification rate, $k_s = k'_s / 2$, k_h is the highlight attenuation rate, $k_h = k'_h / 2$, and k_s and k_h are $\in [0, 1]$.

Let's consider the generation method of "digital images" D_s and D_h . Humans can identify digital for images. This is because their luminance is different from background luminance in some local area. This statement is similar to the following simplest physical model of forming a grayscale image I :

$$I = R * L, (5)$$

In the above formula, L is the brightness of the subject that changes relatively slowly, and R is the reflectance (or albedo) of the subject digital that changes to high frequency. Therefore, the "digital image" is an estimate of reflectance.

A low pass filter is used in a classic Retinex local background (or subject brightness of scene L) to estimate Gaussian blurring, for example. However, it is not very accurate from the physical viewpoint. This is because, among the subject boundaries of low identifiability, the high contrast sharp boundaries are well deteriorated, producing a modest change in L values between subjects with different brightness. A good resolution for the L value is a part of the image for an equivalent light-emitting area, but there is still a problem that is difficult to solve. To compromise this limitation, it is possible to apply filtering that preserves the high contrast sharp boundaries.

There are various types of edge-preserving filters. They are considered primarily as noise suppression filters. C. Tomasi, R. Manduchi [C. Tomasi, R. Manduchi "Bilateral filtering for gray and color images", 1998 IEEE Conference on Computer Vision] proposed the realization of bilateral filters as a set of highly efficient and simple filters:

$$I_f(r, c) = \frac{\sum_{i=-S/2}^{S/2} \sum_{j=-S/2}^{S/2} I(r+i, c+j) * v(i, j) * w(I(r+i, c+j) - I(r, c))}{\sum_{i=-S/2}^{S/2} \sum_{j=-S/2}^{S/2} v(i, j) * w(I(r+i, c+j) - I(r, c))}, (6)$$

For all pixels (r, c) of image I , $S = 3 * \sigma_D$ is the size of the filter opening (domain kernel).

Conventional realization of bilateral filters uses the following Gaussian function for domain processing:

$$v(i, j) = \exp\left(-\frac{i^2 + j^2}{2\sigma_D^2}\right), (7)$$

Also, in case of range processing (aka edge-stop function),

$$w(x) = \exp\left(-\frac{x^2}{2\sigma_R^2}\right) \quad (8)$$

In the above formula, σ_D^2 and σ_R^2 are variances for the corresponding domains and ranges.

The computational complexity of the bilateral filters in the above formula (6) for the image of $N \times N$ size is $O(N^2 * S^2)$, and requires distinct operational resources. Thesis [F. Durand, J. Dorsey's "Fast Bilateral Filtering for the Display of High-Dynamic Images", GIGGRAPH 2002, pages 257 - 266] discloses an effective method to increase the speed of bilateral filters for S above about 30 - 50, depending on FFT execution. A shortcoming of the method of Durand/Dorsey is that execution is complicated as block style or tile style processing.

Therefore, for $S < 30$, it is better to apply a bilateral filter to filter the image first by row and then by column as follows:

$$I_f^*(r, c) = \frac{\sum_{j=-S/2}^{S/2} I(r, c+j) * u(j) * w(I(r, c+j) - I(r, c))}{\sum_{j=-S/2}^{S/2} u(j) * w(I(r, c+j) - I(r, c))},$$

$$I_f(r, c) = \frac{\sum_{i=-S/2}^{S/2} I_f^*(r+i, c) * u(i) * w(I_f^*(r+i, c) - I_f^*(r, c))}{\sum_{i=-S/2}^{S/2} u(i) * w(I_f^*(r+i, c) - I_f^*(r, c))} \quad (9)$$

As it is similar to convolution, the applicant names the bilateral filter as “separable”, although its separability has not been mathematically demonstrated in a strict sense. The computational complexity of the separable bilateral filter is $O(2 * N^2 * S)$.

Let's compare formulas (2) and (3) with the disclosed sharpening method “unsharp mask” of the following formula:

$$I_s = I + a * (I - I_b), \quad (10)$$

In the above formula, a is a constant and I_b is the result of low pass filtering (blurring) of the source image.

According to the reasons described above, images D_s and D_h (estimated reflectance) are functions of the ratio between the image filtered using a bilateral filter and the source image. The Applicant proposes that, depending on the parameters of the bilateral filter, it is possible to achieve an increase in the sharpness of the image. In fact, when Gaussian is used as an edge-stop function, a little sharpening occurs for edges less than or equal to $3\sigma_R$. Edges with larger local contrasts do not change. This is because Gaussian tends to quickly become zero (0) outside of the range $[-3\sigma_R, 3\sigma_R]$. The Applicant proposes using an edge-stop function that is similar to Gaussian on the one hand, and does not tend to become zero so fast. We propose a generalization of the El-Fallah-Ford function [1993 IEEE 27th Conference on Signals, Systems, and Computers, El-Fallah A.I., Ford G.E.'s "Structure preserving inhomogeneous diffusion in image filtering"]:

$$w(x) = \frac{1}{\sqrt{1 + \left| \frac{x}{\sigma_R} \right|^\mu}} \quad (11)$$

In the conventional El-Fallah-Ford function, $\mu=2$ is a function similar to Gaussian in the case of $\mu=6$. The variation of μ in the range of 1 to 6 allows control of the sharpening. FIG. 2 shows the configuration of $w(x)$ for $\mu=2$ and $\mu=6$, and also for Gaussian with the same σ_R . The use of formula (11) with a variant μ is shown in FIG. 3 (steps 301 and 305).

Following formula to understand the use of a general function for a domain kernel:

$$u(x) = \begin{cases} \frac{1}{S}, & |x| \leq \sigma_D \\ 0, & |x| > \sigma_D \end{cases} \quad (12)$$

At that time, the removable bilateral filter is simpler and faster:

$$I_f^*(r, c) = \frac{\sum_{j=-S/2}^{S/2} I(r, c+j) * w(I(r, c+j) - I(r, c))}{S * \sum_{j=-S/2}^{S/2} w(I(r, c+j) - I(r, c))}$$

$$I_f(r, c) = \frac{\sum_{i=-S/2}^{S/2} I_f^*(r+i, c) * w(I_f^*(r+i, c) - I_f^*(r, c))}{S * \sum_{i=-S/2}^{S/2} w(I_f^*(r+i, c) - I_f^*(r, c))} \quad (13)$$

Image I_f filtered by a bilateral filter can be used as an alpha-channel α_s . The negative of I_f can be used as an alpha-channel α_h . It is advantageous to have an opportunity to act tone width on shadows and highlights. The necessary effect is achieved by raising the power t_s to α_s and the power t_h to α_h , and by $t_h \in [1,6]$. Therefore, the formula (4) will be converted as follows:

$$I_\theta(r, c) = I(r, c) + k_s * (1 - I_f(r, c))^{t_s} * (D_s(r, c) - I(r, c)) - k_h * (I_f(r, c))^{t_h} * (I(r, c) - D_h(r, c)) \quad (14)$$

One of the most desirable modifications of D_s and D_h is the following function:

$$D_s(r, c) = \frac{1.3 * I(r, c)}{I_f(r, c) + 3 * \sigma_R} \quad (15)$$

$$D_h(r, c) = \frac{3 * \sigma_R * I_f(r, c)}{1.3 - I(r, c)} \quad (16)$$

These functions are defined as modeling with sufficient sample photos.

It is necessary to consider the color depth of the image being processed and also to substitute the formula (14) with some additional functions in order to prevent placing an acceptable range of luminance values in the image values as follows:

$$I_e(r, c) = f_w(I(r, c) + k_s * (2^n - 1 - I_f(r, c))^{t_s} * f_b(\frac{1.3 * I(r, c)}{I_f(r, c) + 3 * \sigma_R} - \frac{I(r, c)}{2^n - 1}) - k_h * (I_f(r, c))^{t_h} * f_b(\frac{I(r, c)}{2^n - 1} - \frac{3 * \sigma_R * I_f(r, c)}{1.3 - I(r, c)}))$$

$$f_b(x) = \begin{cases} x & : x \geq 0 \\ 0 & : x < 0 \end{cases}$$

$$f_w(x) = \begin{cases} x & : x \leq (2^n - 1) \\ 2^n - 1 & : x > (2^n - 1) \end{cases} \quad (17)$$

In the above formula, I_e is dependent only on I and I_f , and therefore, we can see that I_e operation time can be reduced by configuring 2D (dimension) lookup table (LUT). If memory resources are limited and it is not possible to store $(2^n - 1) * (2^n - 1)$ matrix, then a LUT that is decimated with the next bilinear interpolation between the decimated values can be configured. For example, when n is 8, results using a LUT of size 52 x 52 or 86 x 86 visually are rarely discernible, such as when using a 256 x 256 LUT.

Figure 3 illustrates a schematic diagram of the basic work steps of the method. First of all, the noise of each of the R, G, and B channels is suppressed (step 301). When correcting the shadows and highlights in these tones, the noise level and JPEG artifacts grow. It is necessary to perform the filtering of noise prior to shadow/highlight correction. Bilateral filters are for noise suppression. Tomasi and Manduchi proposed calculating the range distance in the lab color space and also disclosed with respect to possible color halos when filtered by each of R, G, and B channels [1998 IEEE Conference on Computer Vision, C. Tomasi, R. Manduchi's "Bilateral Filtering for Gray and Color Images"]. If such an S is small, the haloes are rarely identifiable and channel filtering may be allowed. The Applicant proposes using a bilateral filter according to Formulas (13) and (11) having parameters $\mu = 6$, S_3 , and $\sigma_R = 0.02 * (2^n - 1)$ or proposes estimating σ_R in an adaptable manner. Other variants are for calculating distance in the lab color space or in the gray-channel.

A global contrast adjustment is performed for each of the R, G, and B channels in step 302. FIG. 4 shows a schematic diagram of a global contrast adjustment. In step 303, the color image is converted from R, G, B to the maximum luminance channel as follows:

$$I(r, c) = \max(R(r, c), G(r, c), B(r, c)). \quad (18)$$

In addition, in step 304, shadow/highlight correction parameters (k_s, k_h, t_s, t_h) are defined. To define the correction parameters, it is possible to interactively set parameters using similar automatic classifiers as proposed in Russian Publication No. 2005/112311 of I. Safonov or using an input device. Also in step 305, the filtering is done by a separable bilateral filter according to the Formulas (13) and (11) with the filter parameters $\mu=2$, $S=15$, and $\sigma_R=0.1*$

$(2^n - 1)$. In step 306, shadow and highlight correction is performed according to the Formula (17). As a result of the correction, the sharpening increases slightly. In addition, in step 307, the corrected image is converted to color space RGB as follows:

$$R' = R * I_e / I, G' = G * I_e / I, B' = B * I_e / I. \quad (19)$$

The formulas provided maintain the contrast ratios of RGB channels between each other, and thereby, the color and saturation of the color image remains constant.

The correction of grayscale images is performed similarly, but steps 303 and 307 are excluded.

FIG. 4 shows a schematic diagram of a global contrast adjustment. First of all, in step 401, the global histograms H_R , H_G , and H_B of intensity of R, G, B are calculated. A decision is also made on the need for global contrast adjustment in step 402. If the histogram values for the two minimum or two maximum intensity values are zero,

Если $(H_R[0]=0 \text{ and } H_R[1]=0 \text{ and } H_G[0]=0 \text{ and } H_G[1]=0 \text{ and } H_B[0]=0 \text{ and } H_B[1]=0)$
or $(H_R[2^n-3]=0 \text{ and } H_R[2^n-2]=0 \text{ and } H_G[2^n-3]=0 \text{ and } H_G[2^n-2]=0 \text{ and } H_B[2^n-3]=0 \text{ and } H_B[2^n-2]=0)$,

a global contrast adjustment is performed.

In step 403, a range of low boundaries for a global contrast adjustment is defined by the following formula:

$$\begin{aligned} low = \min(& T, \min\{i \mid H_R[i] \geq H_0\}, \min\{i \mid \sum_{k=0}^i H_R[k] \geq C_0\}, \min\{i \mid H_G[i] \geq H_0\}, \min\{i \mid \sum_{k=0}^i H_G[k] \geq C_0\}, \\ & \min\{i \mid H_B[i] \geq H_0\}, \min\{i \mid \sum_{k=0}^i H_B[k] \geq C_0\}), \end{aligned} \quad (20)$$

In the above formula, H_0 , C_0 and T are the threshold values according to histogram level, histogram region and strength. Threshold T is put in to avoid excessive darkening of the image.

The range of high boundaries for global contrast adjustment is defined in step 404 as follows:

$$\begin{aligned} high = \max(& \max\{i \mid H_R[i] \geq H_1\}, \max\{i \mid \sum_{k=i}^{2^n-1} H_R[k] \geq C_1\}, \max\{i \mid H_G[i] \geq H_1\}, \max\{i \mid \sum_{k=i}^{2^n-1} H_G[k] \geq C_1\}, \\ & \max\{i \mid H_B[i] \geq H_1\}, \max\{i \mid \sum_{k=i}^{2^n-1} H_B[k] \geq C_1\}), \end{aligned} \quad (21)$$

In the above formula, H_1 and C_1 are the threshold values according to histogram region and strength. FIG. 5 shows the threshold values for the histogram.

In addition, in step 405, a linear contrast extending to all available ranges is performed as follows:

$$\begin{aligned} R(r,c) &= (2^n-1) * (R(r,c) - low) / (high - low) \\ G(r,c) &= (2^n-1) * (G(r,c) - low) / (high - low) \\ B(r,c) &= (2^n-1) * (B(r,c) - low) / (high - low) \end{aligned} \quad (22)$$

FIG. 6 is a diagram illustrating a correction example, wherein a) is a source image, b) is an enhanced image ($k_s = 0.5$, $k_h = 0.5$, $t_s = 2$, $t_h = 2$), c) is the result of a bilateral filtering, d) is the reflectance estimate for a shadow calculated using the formula (15), and e) is the reflectance estimate for a highlight calculated using the formula (16). The shadow was corrected on the left part and upper part of the photo, and the highlight was corrected on the right part.

FIG. 7 is a diagram showing the impact of noise filtering on the quality of photographs, wherein a) is a portion of the enhanced image (6a) without noise suppression, and b) is a portion of the enhanced image with noise suppression. The change in skin tone of a portion of the image (6g) looks smoother and more enjoyable than in the image (6f). The dispersion of a portion of the image (6g) is less than or equal to the dispersion of the image (6f) for all color channels.

FIG. 8 is a diagram showing the advantages of the proposed method above the Adobe Photoshop shadow/highlight resolution, wherein a) is the result of the Photoshop shadow/highlight, b) is the photograph enhanced by the proposed method, c) is the original photograph, and d) is the schematic diagram of the luminance profile according to the line segments AB . The Adobe Photoshop Shadow/Highlight resolution produces a halo effect, but there is no halo effect and noise level is lower in the proposed method.

Best Variation of Implementation of the Invention

The proposed method may be implemented in printing firmware or software or image capture hardware.

Effects of the Invention

The proposed method can be applied to the enhancement of photographs while printed on the photo printer, and in particular, the methods can be applied to enhance the quality of the photographs while being printed on the photo printer. In particular, the methods of the present invention can be applied to the correction of color and grayscale photographs having a low dynamic range in shadows and/or highlights, for example, for the correction of photos with backlit defects. With some changes, it can be used to enhance the quality of images captured by digital still cameras, cell phones with cameras, camcorders and TV-cameras. Modifications for display are also possible.

Concise Explanation of the Drawings

Figure 1 is a basic configuration diagram of the system.

FIG. 2 is a configuration diagram of different edge-stop functions.

FIG. 3 is a schematic diagram showing enhancement steps.

FIG. 4 is a schematic diagram showing a global contrast adjustment.

FIG. 5 is a graph showing the threshold values for contrast stretching shown in the histogram.

FIG. 6 is a sample diagram of enhancement.

FIG. 7 is a sample diagram of noise suppression.

FIG. 8 is a diagram showing the results of the comparison of Adobe Photoshop CS shadow/highlight results with the proposed method.

Drawings

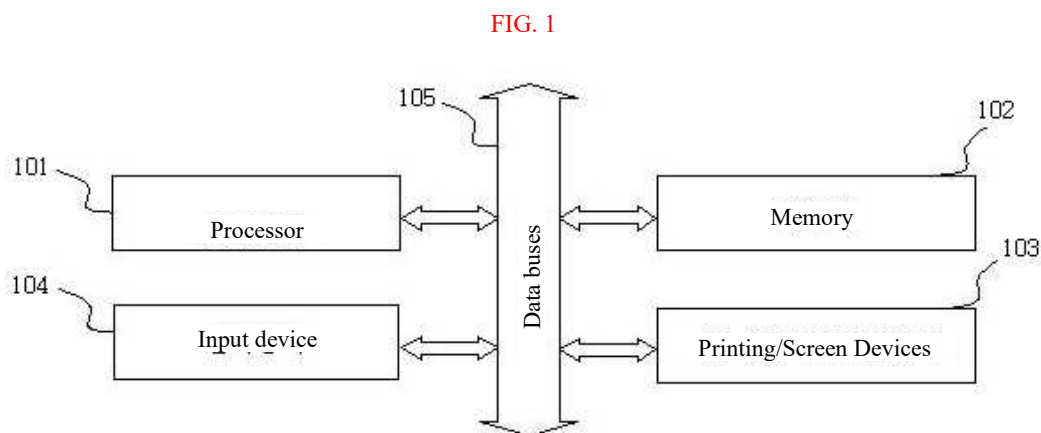


FIG. 2

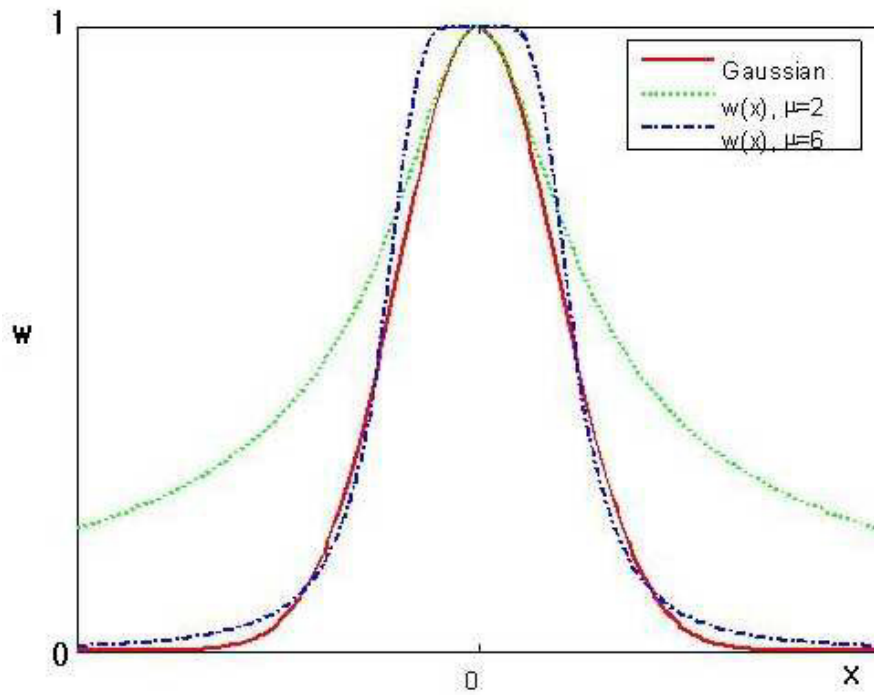


FIG. 3

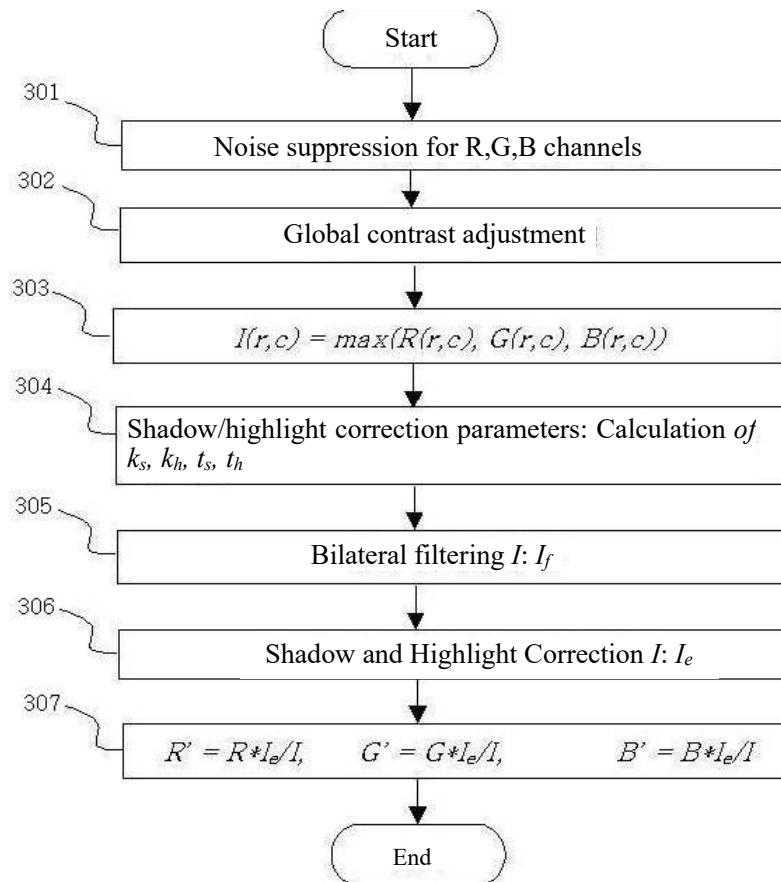


FIG. 4

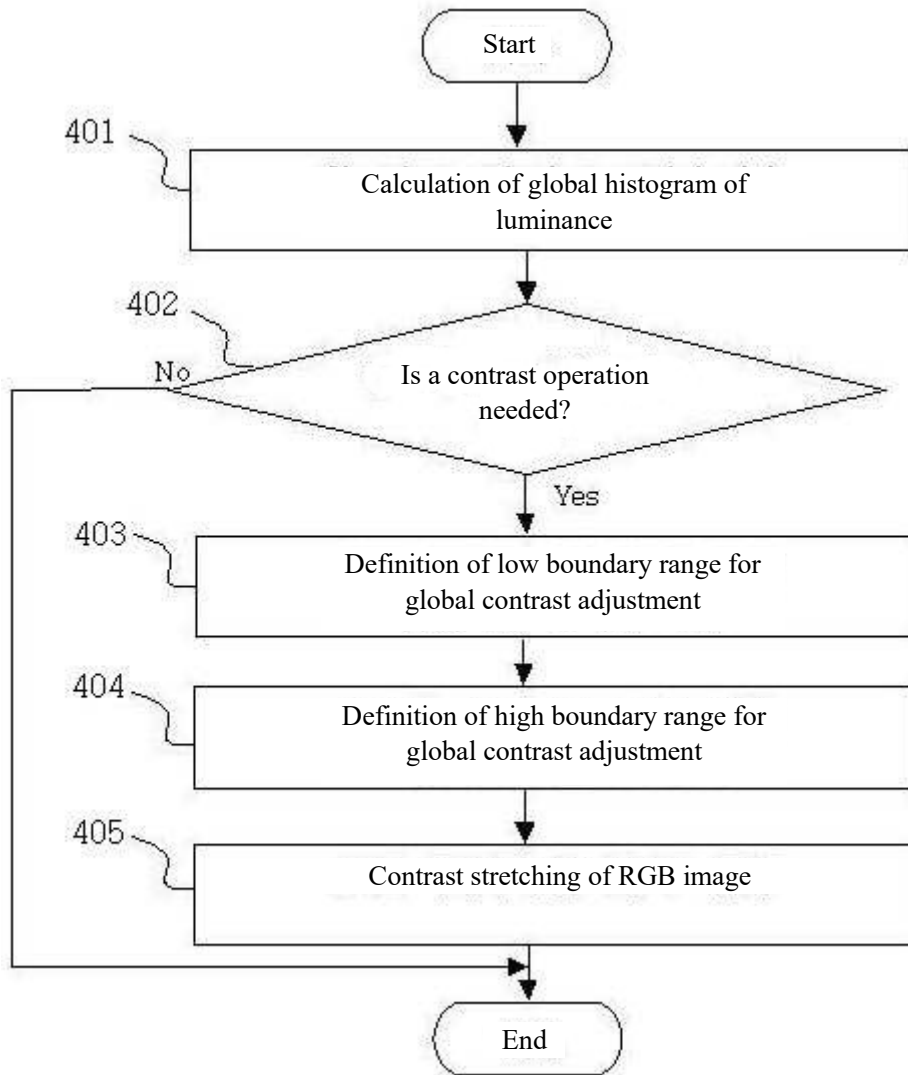


FIG. 5

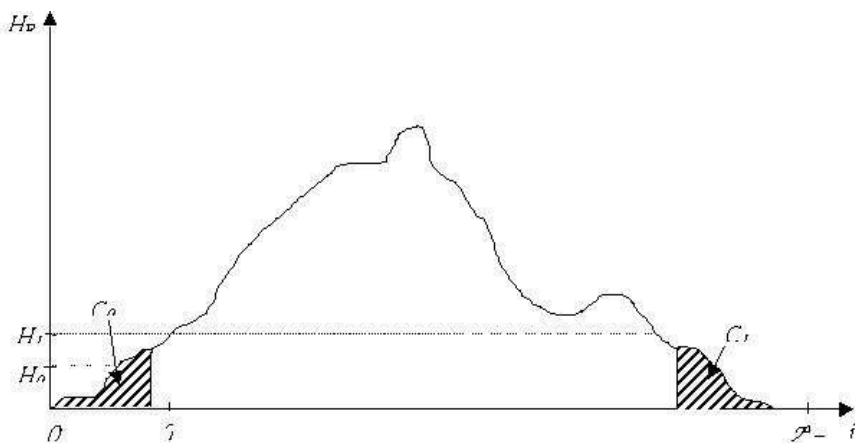


FIG. 6

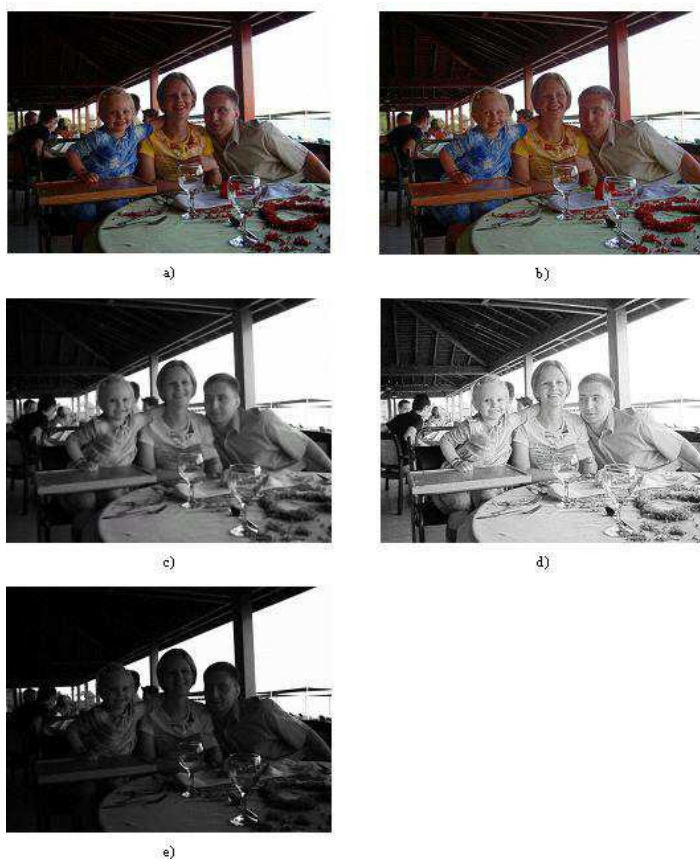
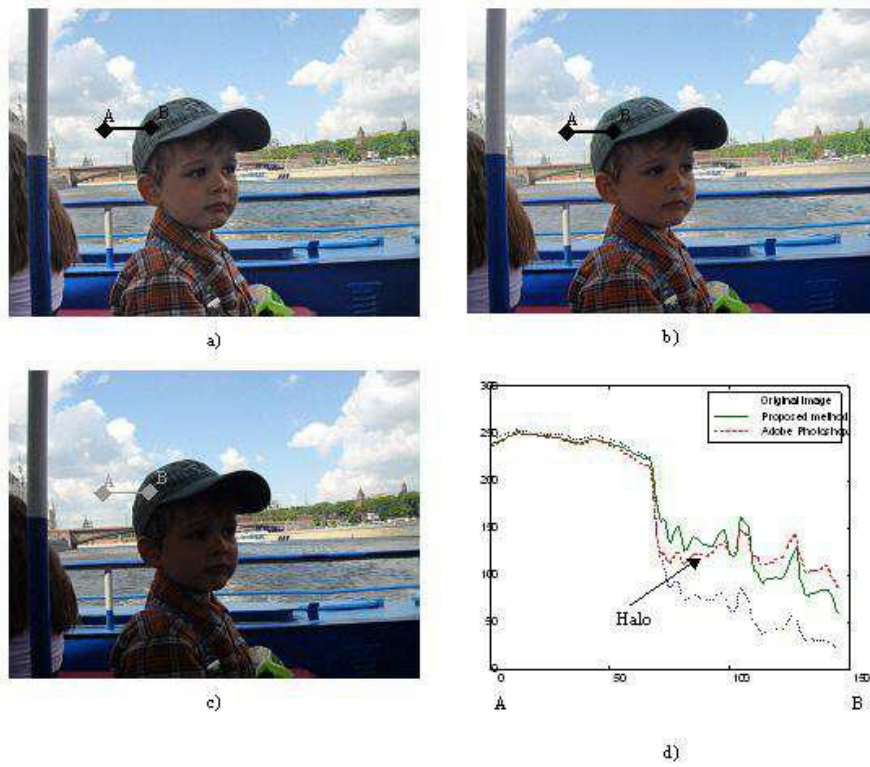


FIG. 7



FIG. 8



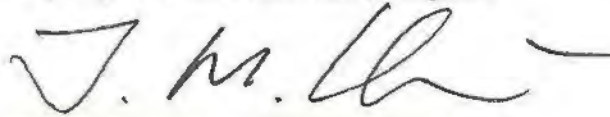
DECLARATION OF JONG MAN CHOI

I, Jong Man Choi, pursuant to 28 U.S.C. § 1746, hereby declare as follows:

1. I am a Korean translator at TransPerfect, Inc.
2. I submit this declaration to certify the accuracy of the English translation of KR20070046010A.
3. My statements are based on personal knowledge. I personally prepared the translation of KR20070046010A from Korean to English. If called as a witness about the facts contained in these statements, I could testify competently based on such personal knowledge.
4. Attached as Exhibit A is a true and accurate copy of KR20070046010A.
5. Attached as Exhibit B is a true and accurate copy of the English translation KR20070046010A that I prepared.
6. The KR20070046010A Translation is, to the best of my ability, a true and accurate translation of KR20070046010A from Korean to English.
7. All statements made herein of my own knowledge are true, and all statements made on information and belief are believed to be true. Further, I am aware that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. § 1001. I declare under penalty of perjury that the foregoing is true and correct.
8. I also understand that by submitting this declaration I may be asked to appear for a deposition asking me questions limited to the material in my declaration. With my signature below, I agree to make reasonable efforts to make myself available for such a deposition at a reasonable place and time of my choosing.

* * *

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge. Executed on February 15, 2024 in Centreville, Virginia.



Jong Man Choi

Sworn to before me this

February 15, 2024



Signature, Notary Public

County/City of Fairfax
Commonwealth/State of Virginia

The foregoing instrument was acknowledged
before me this 15 day of February
2024, by

Jong Man Choi
(name of person seeking acknowledgement)

[Signature]
Notary Public
My Commission Expires: Aug 31, 2027

Stamp, Notary Public

