Automatic correction of amateur photos damaged by backlighting

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Abstract

In this paper we consider a problem of enhancement of amateur photos damaged by backlighting for printing. The purpose of correction is to make photos more pleasant for an observer. Photos with exposure problems and with poorly distinguishable details in dark areas are main subject of our research. Our approach is based on contrast stretching and alpha-blending of both brightness of the initial image and estimations of reflectance. For obtaining reflectance estimation a simplified illumination model is used. The luminance is estimated using bilateral filter. Reflectance is estimated using heuristic functions of ratio between brightness of the initial image and estimation of luminance. The correction parameters are chosen adaptively based on histogram analysis. Noise suppression and some sharpening occur during correction. Also the time and memory optimization issues are considered. Recursive separable bilateral filter is applied to speed up the algorithm. The quality of the algorithm is evaluated by surveying of observer's opinions and by comparisons with already existing software and hardware solutions for local shadow correction.

Keywords: *Adaptive photo enhancement, shadow correction, recursive separable bilateral filter.*

1. INTRODUCTION

Market of home photo printing quickly grows now, and quality of printed photo became a very important issue. A lot of amateur photos are damaged by various defects and need to be enhanced to be more pleasant for observers.

We have collected a representative set of the typical consumer photos taken by various Digital Still Cameras and cameraphones. Total number of test photos is about 6000. The following 7 items were selected as the most noticeable defects of photos:

- various exposure problems;
- color misbalance;
- blurring;
- noise;
- JPEG artifacts;
- flash defects;
- color fringing.

We discover that majority of defected photos are affected by various types of exposure defects. Sometimes photos have low global contrast, mostly because of underexposure, sometimes because of overexposure, but a lot of photos which had been taken by digital camera, for example those affected by backlighting, have low dynamic range in dark areas. Figure 1 demonstrates example of photo damaged by backlighting.

Figure 1: Example of photo damaged by backlighting.

Thus, the development of image enhancement method which includes global and local correction of contrast is an important and topical task. It is desirable to make processing in automatic mode.

2. RELATED WORK

There are many publications dealing with global contrast and brightness adjustment. However majority are devoted to global correction and do not consider correction of local contrast.

In present time general way for local contrast correction is application of the simplest physical model of forming a grayscale image I:

$$I = R \times L, \tag{1}$$

where L is luminance of objects and varies relatively slowly, R is reflectance (or albedo) of objects details which varies with high frequency [1]. The given model does not take into account possible presence of light sources, specular reflection (only diffusive Lambert reflection), and the formation of shadows from objects on the image. In spite of disadvantages, the model is quite applicable to a wide class of the images and is used in methods described below. In these methods reflectance is estimated by the different ways but always as ratio of I and L.

Several papers [2, 3, 4, 5, 6, 7] depict a way of correction of dark tones based on various modifications of MultiScale Retinex (MSR) algorithm. Classical MSR is determined as:

$$I_e = \sum_{n=1}^{N} \omega_n \times (\log(I) - \log(LPF_n(I))), \tag{2}$$

where LPF - Gaussian blur with various σ. Methods based on classical MSR have a high computational complexity.

In Sobol's approach [2] the optimized algorithm of calculation is used for realization of Gaussian blur. Also, the set of thresholds is entered to suppress halo. Briefly the idea of this approach is the following. The modified MSR is carried out for the brightness channel. Brightness is calculated as max(R, G, B). Result of modified MSR is called a mask. The mask is added to R, G and B channels. Given method is used in HP "Adaptive Lighting" technology.

Another interesting modification of MSR is presented in paper [3]. Authors consider the problems of improvement of color appearance and increasing of processing speed.

Intuitively clear and rather simple method of shadow and highlight correction is described in [8]. The mask is created as a result of strong blurring of brightness channel. For such blurring, linear low-pass filter is applied. Then each RGB component is transformed using a family of Tone Reproduction Curves where curve shape depends on mask value. For example, for image normalized to the range [0, 1] the expressions look like:

$$R=(R)^{2^{(1-2Mask)}};G=(G)^{2^{(1-2Mask)}};B=(B)^{2^{(1-2Mask)}}. \quad (3)$$

International patent application [9] describes method of image enhancement based on Orthogonal Retino-Morphic Image Transform (ORMIT):

$$I_e=\sum_{i=0}^{N}a_i(I)\times LPF(P_i(F(I)))\times Q_i(F(I))+b(I), \quad (4)$$

where $P_i(x)$ is orthogonal basis of functions of x defined in the range $0<x<1$, Q_i are anti-derivatives of P_i, or an approximation thereto, LPF is operator of low-pass spatial filtering, F is weigh function which is similar to gamma correction, N is number of bands: $N<<n$ where n is a color depth on channel, a and b are constants specific for each band. Choice of the appropriate P_i allows increasing of local contrast. The given method is used in the technology Nikon "D-Lighting".

The paper [10] describes the method of shadow correction which also is based on simplest model (1):

$$I_e=S\times(R+a\times L), \quad (5)$$

where a is attenuation constant, S is linear scaling operator that scales the results to the full signal range, L is result of applying edge-preserving filtering, R is function of ratio between brightness of source image and L. Edge-preserving filtering is carried out for each scan-line of the image, operation of the filter is based on estimation of noise level of the image. Noise is suppressed in brightness channel, but noise in chromaticity channel remains. The advantage of the method is the absence of the distinguishable halo.

Notice that a set of the High Dynamic Range Imaging (HDRI) [11, 12, 13] contrast reduction techniques also can be used for correction of backlight photos. However, these algorithms also influence middle and highlight tones too. This can lead to unwanted tone artifacts, especially in highlights.

Current technologies used for local correction in dark areas have set of essential drawbacks: a lot of methods have high computational complexity; some algorithms lead to halo-effect near contrast sharp boundaries; the application of existing algorithms increases noise and JPEG artifacts in shadow areas; posterization and some unwanted effects sometimes are possible; some existing solutions are not adaptive; sometimes color distortions are present.

3. SHADOW CORRECTION METHOD

3.1 Basic idea

Let us consider basic ideas for shadow correction on grayscale photo, with brightness values ranging from 0 to 1. Photos affected by backlighting have low dynamic range in shadow areas but have normal global contrast. For the observer it results in difficulties distinguishing details especially in shadow where tones are darker than in properly exposed areas. Therefore, it is necessary to increase local contrast and brightness in shadow areas.

Let us take an "image of details" D_s with high local contrast in shadow, i.e. an images with well distinguishable details in dark areas. Then it is possible to increase local contrast and brightness of the source image I using the following alpha-blending of I and D_s:

$$\begin{aligned}I_e(r,c)&=I(r,c)\times\alpha_S(r,c)+(1-\alpha_S(r,c))\times(k_S\times D_S(r,c)+\\&+(1-k_S)\times I(r,c)),\end{aligned} \quad (6)$$

for all pixels (r,c) of image I, where α_s is an alpha-channel in a sense of transparency, which values are close to 1 in bright areas, and close to 0 in dark areas; factor k_s controls level of amplification of local contrast in shadow, $k_s \in[0, 1]$. After opening brackets, we get the following formula:

$$I_e(r,c)=I(r,c)+k_S\times(1-\alpha_S(r,c))*(D_S(r,c)-I(r,c)). \quad (7)$$

Consider one of the approaches for computation of "image of details" D_s. Human can distinguish details in an image because their brightness differs from background brightness in some local area. This statement is similar to the simplest physical model of forming a grayscale image according to (1). Thus, "image of details" is estimation of reflectance.

3.2 Estimation of reflectance

In classical Retinex local background (or object illumination of scene - L) is estimated using low pass filters, for example, Gaussian blurring. However, this is not quite correct from the physical point of view, because apart of the low distinguishable objects boundaries highly contrasting sharp boundaries are degraded as well, producing smooth variation of L between objects with different illumination. Good solution for L is segmentation of the image for equally illuminated areas, but for now it is a hard problem to solve. To compromise with this limitation it is possible to apply filtration, which preserves highly contrasting sharp boundaries [2, 10].

There exist various types of edge preserving filters. Mainly they are considered as noise-suppressing filters. Tomasi and Manduchi [14] described a family of highly effective and relatively simple in realization filters – bilateral filter:

$$\underset{\forall(r,c)}{I_f(r,c)}=\frac{\sum_{i=-S/2}^{S/2}\sum_{j=-S/2}^{S/2}I(r+i,c+j)\times v(i,j)\times w(I(r+i,c+j)-I(r,c))}{\sum_{i=-S/2}^{S/2}\sum_{j=-S/2}^{S/2}v(i,j)\times w(I(r+i,c+j)-I(r,c))}, \quad (8)$$

where S is size of the filter aperture (domain kernel).

Traditional realization of the bilateral filter uses Gaussian functions for domain processing:

$$v(i,j) = \exp(-\frac{i^2 + j^2}{2\sigma_D^2}), \quad (9)$$

and for range processing (so-called, edge-stop function):

$$w(x) = \exp(-\frac{x^2}{2\sigma_R^2}), \quad (10)$$

where σ_D^2 and σ_R^2 are dispersions for domain and range correspondingly.

We suggest that depending on parameters of the bilateral filter it is possible to achieve some increase of sharpness in the image. Actually, if Gaussian is used as edge-stop function then some sharpening occurs for edges less than $3\sigma_R$. The edges which have greater local contrast do not change, because Gaussian rapidly tends to zero outside the range $[-3\sigma_R, 3\sigma_R]$. We propose to use edge-stop function, which on the one hand is similar to Gaussian and on the other hand does not tend to zero so rapidly. It is proposed to generalize El-Fallah-Ford function [15]:

$$w(x) = \frac{1}{\sqrt{1 + \left|\frac{x}{\sigma_R^2}\right|^{\mu}}}. \quad (11)$$

In classical El-Fallah-Ford μ=2, for μ=6 this function is similar to Gaussian. Variation of μ in a range from 1 to 6 allows controlling sharpening. Figure 2 shows a plot of $w(x)$ for μ=2 and μ=6, also Gaussian with the same σ_R.

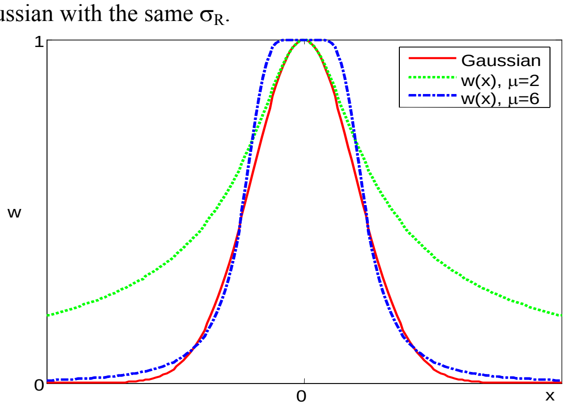


Figure 2: Plots of the different edge-stop functions.

Computation of R in (1) is an ill posed problem [12] for images, but it is clear that estimation of reflectance is a function of ratio between brightness of the source image and estimation of lightness, and it needs some regularization. During modeling with two hundreds of sample photos damaged by backlighting we found out a heuristic formula for estimation of reflectance D_s:

$$\underset{\forall(r,c)}{D_s(r,c)} = \frac{1.3 \times I(r,c)}{I_f(r,c) + 3 \times \sigma_R}, \quad (12)$$

where I is brightness of source image, I_f is estimation of lightness (I filtered using bilateral filter with σ_R=0.1). Application of (12) makes details in shadow well distinguishable in the image.

3.3 Correction of brightness channel

Correction of brightness channel of a photo is performed using expression (7). Estimation of lightness I_f can be used as an alpha channel α_s. It is expedient to have an opportunity to control tone width for shadow. The necessary effect is achieved by raising α_s to the power t_s, $t_s \in [1, 6]$. Also (7) is supplied with some additional functions, to prevent image values to leave the allowable range of brightness values. Thus, the (7) will be transformed to the formulae:

$$\underset{\forall(r,c)}{I_e(r,c)} = f_w(\ I(r,c) + k_s \times (1 - I_f(r,c))^{t_s} \times$$
$$\times f_b(\frac{1.3 \times I(r,c)}{I_f(r,c) + 3 \times \sigma_R} - I(r,c))),$$
$$f_b(x) = \begin{cases} x, & x \ge 0 \\ 0, & x < 0 \end{cases}, \quad (13)$$
$$f_w(x) = \begin{cases} x, & x \le 1 \\ 1, & x > 1 \end{cases},$$

where I is normalized to the range [0, 1], I_f is result of bilateral filtering, k_s is shadow amplification factor, t_s is parameter for tuning of tone width, σ_R^2 is dispersion of bilateral filter for range.

3.4 Adaptive choice of parameters

Adaptive choice of parameters is based on histograms analysis. Parameters for global contrast adjustment and shadow correction are defined separately. First of all histograms H_R, H_G, H_B of intensity of R,G,B channels and histogram H of brightness of thumbnail of source image are calculated.

Low boundary of the range for global contrast adjustment is defined as following:

$$low = \min(\ T,$$
$$\min\{i \mid H_R[i] \ge H_0\}, \min\{i \mid \sum_{k=0}^{i} H_R[k] \ge C_0\},$$
$$\min\{i \mid H_G[i] \ge H_0\}, \min\{i \mid \sum_{k=0}^{i} H_G[k] \ge C_0\}, \quad (14)$$
$$\min\{i \mid H_B[i] \ge H_0\}, \min\{i \mid \sum_{k=0}^{i} H_B[k] \ge C_0\}\ ),$$

where H_0, C_0 and T – threshold values accordingly to histogram level, histogram area and intensity. Threshold T is entered with the purpose of avoid the excessive image darkening.

The high boundary of the range for global contrast adjustment is defined as following:

$$high = \max($$
$$\max\{i \mid H_R[i] \ge H_1\}, \max\{i \mid \sum_{k=i}^{1} H_R[k] \ge C_1\},$$
$$\max\{i \mid H_G[i] \ge H_1\}, \max\{i \mid \sum_{k=i}^{1} H_G[k] \ge C_1\}, \quad (15)$$
$$\max\{i \mid H_B[i] \ge H_1\}, \max\{i \mid \sum_{k=i}^{1} H_B[k] \ge C_1\}\ ),$$

where H_1 and C_1 - threshold values for histogram area and intensity correspondingly.

Choice of features for local shadow correction is based on the following considerations. Backlit photos are characterized by high peaks in shadows and/or highlights and presence of gap in midtones. Usually histogram of photos with low local contrast in shadows is characterized by asymmetry in shadows: its center in shadows is dislodged nearer to the origin of the brightness range. The typical histogram of photo damaged by backlighting is shown on figure 3.

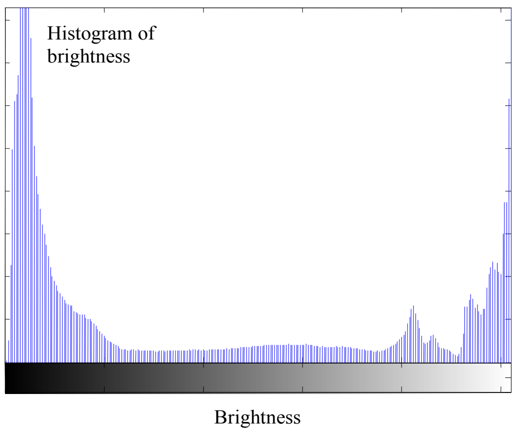


Figure 3: Typical histogram of photo damaged by backlighting.

The following features normalized to the range [0, 1] are calculated for image size *MxN*. Part of tones in the shadows/midtones:

$$S_1 = \sum_{[0,1/3]} H(i)/(M \times N)\,, \qquad (16)$$

$$S_2 = \sum_{(1/3,2/3]} H(i)/(M \times N)\,. \qquad (17)$$

Part of tones in the first half and second half of shadows:

$$S_{11} = \sum_{[0,1/6]} H(i)/(M \times N)\,, \qquad (18)$$

$$S_{12} = \sum_{(1/6,1/3]} H(i)/(M \times N)\,. \qquad (19)$$

Ratio of the histogram maximum in shadows/ midtones/highlights to global histogram maximum:

$$M_1 = \max_{[0,1/3]}(H(i)) / \max_{[0,1]}(H(i))\,, \qquad (20)$$

$$M_2 = \max_{(1/3,2/3]}(H(i)) / \max_{[0,1]}(H(i))\,, \qquad (21)$$

$$M_3 = \max_{(2/3,1]}(H(i)) / \max_{[0,1]}(H(i))\,, \qquad (22)$$

Location of the histogram maximum in shadows/ highlights:

$$P_1 = l \mid H(l) = \max_{[0,1/3]}(H(i))\,, \qquad (23)$$

$$P_3 = l \mid H(l) = \max_{(2/3,1]}(H(i))\,. \qquad (24)$$

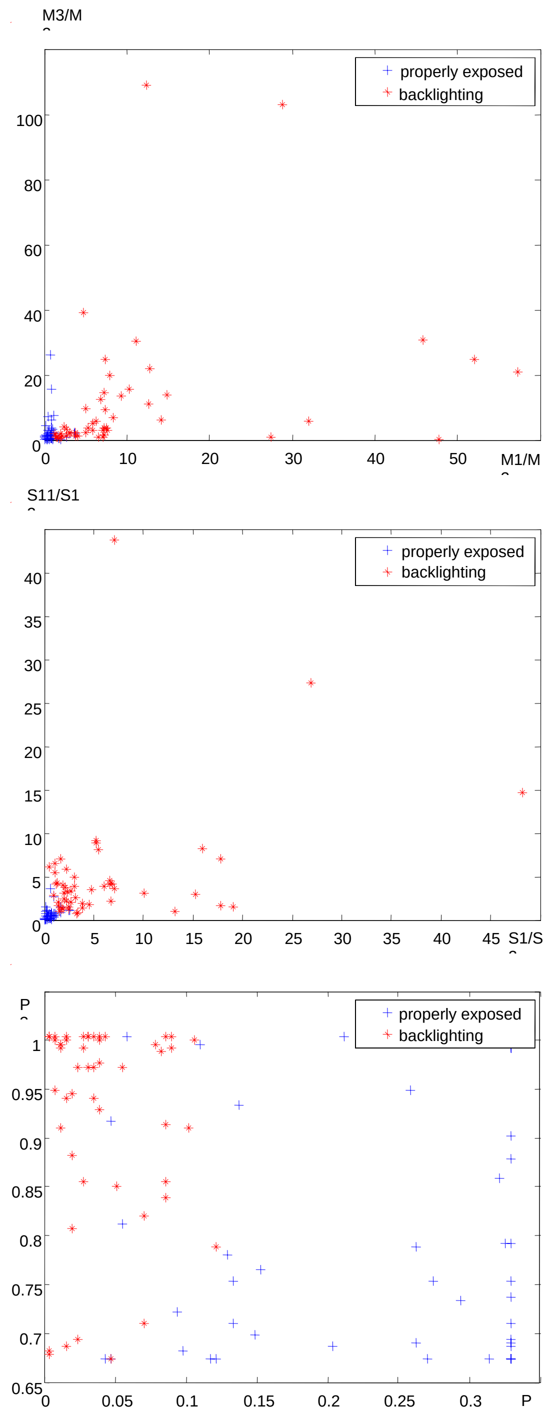


Figure 4: Plots of features for properly exposed photos and photos with backlit.

Figure 4 demonstrates plots of features for 50 properly exposed photos and 50 photos with backlit. Obviously, it is possible to construct a classifier for backlit photos detection. Choice of shadow amplification factor is a little more complicated task. We constructed a decision tree which tests a set of logical conditions and defines shadow amplification factor. Example of logical condition the following: if (M_3>M_2) and (M_3>M_1) and ($P_3 > 0.98$)

and (P_1 < 0.1) and (S_1/S_2 > 1.3) and (S_{11} > S_{12}) then k_s = 0.7. Number of conditions exceeds 20 and we decided that presenting full decision tree is not appropriate.

Described solution is fast enough and provides acceptable results, although it gives only several discrete values of k_s. Implementation of more sophisticated algorithms for determination of k_s is a subject of future research.

3.5 General workflow

Figure 5 shows the flow chart of correction steps. During correction of shadow noise level and JPEG artifacts in these tones are amplified. For this reason filtration of noise is required before correction. The bilateral filter is intended for noise suppression. Tomasi and Manduchi proposed to calculate range distance in *Lab* color space and wrote about possible color halos on filtration by each R, G, B channels [14]. However for small *S* these halos are almost indistinguishable and RGB channel-wise filtering is allowable. We propose to use for noise filtering S=3, σ_D = 100, μ=6 (see expression (11)) and σ_R in the range [0.02, 0.04] depending on noise level.

Next correction parameters are chosen adaptively.

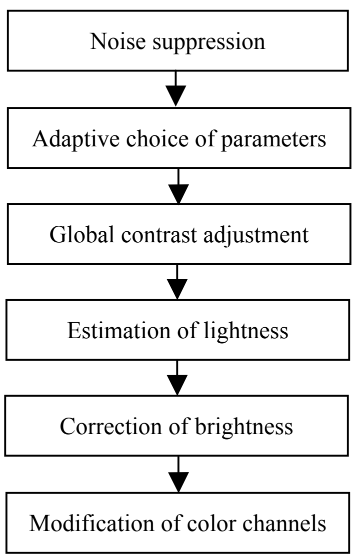


Figure 5: Flow chart of the correction.

For proper shadow correction normal global contrast is necessary. Thus global contrast adjustment is required for each R, G, B channels before shadow correction is applied. We propose using simple linear contrast stretching:

$$R'(r,c) = (R(r,c) - low)/(high - low),$$
$$G'(r,c) = (G(r,c) - low)/(high - low), \qquad (25)$$
$$B'(r,c) = (B(r,c) - low)/(high - low),$$

where *low* and *high* are boundaries of contrast range.

For next stages it is necessary to extract brightness from image. One of the most preferable variant is the following:

$$I(r,c) = \max(R(r,c), G(r,c), B(r,c)) . \qquad (26)$$

Estimation of lightness is result of bilateral filtering *I* with *S* in the range [9, 15], σ_D = 100, μ=5 and σ_R=0.1. Choice of S is trade-off from time performance and quality of the algorithm. Farther *I* is corrected according to (13).

The final stage is modification of color channels as following:

$$R_e(r,c) = R'(r,c) * I_e(r,c) / I(r,c) ,$$
$$G_e(r,c) = G'(r,c) * I_e(r,c) / I(r,c) , \qquad (27)$$
$$B_e(r,c) = B'(r,c) * I_e(r,c) / I(r,c) .$$

The given expressions keep of constant rations between RGB channels with each other, accordingly keeps constant hue and saturation of the color image.

Similar approach for modification of color channels is given in [13]: initial color value is divided by initial brightness, this ratio raised in the power between 0.4 and 0.6, and after that multiplied by corrected brightness. We consider that raising to the power is not appropriate step, because it leads to some desaturation of a photo. Interesting method for modification of color channels is proposed in [16].

Figure 6 illustrates the correction example: (a) initial color photo, (b) corrected photo, (c) result of bilateral filtering, and (d) estimation of reflectance for shadow, which is calculated using (12).

4. RECURSIVE SEPARABLE BILATERAL FILTER

We implemented the proposed method in C++. For profiling we measured a count of processor ticks on processing of 5 MPix photo on Pentium IV 3.2 GHz processor using release build of our application. Total processing time of 5MPix (2592x1944) photo is about 6 sec. Bottleneck problem is bilateral filtering, so time optimization of the stage is required.

Computational complexity of bilateral filtering in (8) with domain kernel of the size *S* for an image of size *N* by *N* is estimated as $O(N^2S^2)$, and requires significant computational resources.

Effective method for speeding up bilateral filtering for *S* about 30-50 or more depending on FFT implementation is presented in [16]. It is worthwhile to apply bilateral filter to filter the image first row-wise, and then column-wise:

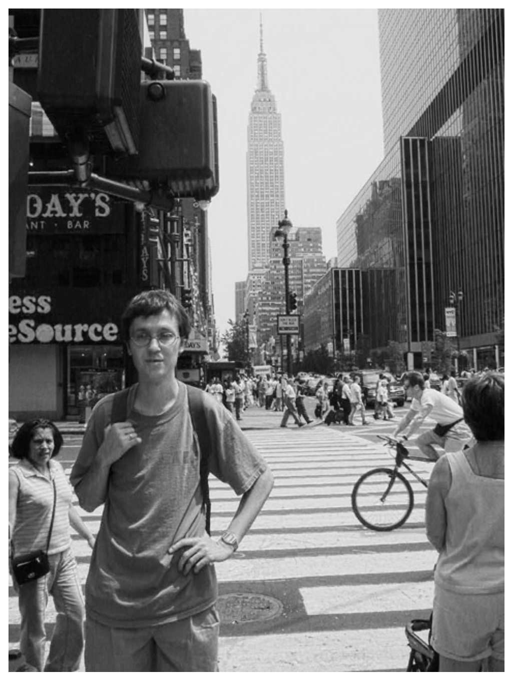
$$\underset{\forall(r,c)}{I_r(r,c)} = \frac{\sum_{j=-S/2}^{S/2} I(r,c+j)\times u(j)\times w(I(r,c+j)-I(r,c))}{\sum_{j=-S/2}^{S/2} u(j)\times w(I(r,c+j)-I(r,c))},$$
$$\underset{\forall(r,c)}{I_f(r,c)} = \frac{\sum_{i=-S/2}^{S/2} I_r(r+i,c)\times u(i)\times w(I_r(r+i,c)-I_r(r,c))}{\sum_{i=-S/2}^{S/2} u(i)\times w(I_r(r+i,c)-I_r(r,c))}. \qquad (28)$$

By analogy to convolution we'll name such filter "separable", though separability of the bilateral filter in mathematical sense is not proved rigorously. The same way for speeding up bilateral filtering and the same name is used in [18]. Computational complexity of the separable bilateral filter is $O(2N^2S)$ and for

a)

b)

c)



d)

Figure 6: Example of correction.

S<100 separable filter is faster than [17] piecewise-linear bilateral filter.

Non-recursive and recursive implementations of the bilateral filter demonstrate close results. Computational complexity of the separable recursive bilateral filter is $O(2N^2S)$ too, but additional memory buffers are not required, thus overall performance of the method is increased. For recursive implementation I, I^*_f, I_f in the expression (28) are the same two-dimensional array.

Dispersion σ_D^2 in (11) is large enough. For domain kernel of the size S it is better to use flat function instead of Gaussian. In this case recursive separable bilateral filter is even simpler and faster:

$$I_f(r,c) = I(r,c), \quad \forall(r,c)$$

$$I_f(r,c) = \frac{\sum_{j=-S/2}^{S/2} I_f(r,c+j) \times w(I_f(r,c+j) - I_f(r,c))}{S \times \sum_{j=-S/2}^{S/2} w(I_f(r,c+j) - I_f(r,c))}, \quad \forall(r,c) \tag{29}$$

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

In addition we propose preliminary calculation of look up table with values of the edge-stop function w(x) according to (11). Total processing time of 5MPix photo after optimization of bilateral filtering is about 1 sec.

5. RESULTS

We used two approaches for evaluating of the quality of the proposed method. At first we have compared the proposed method with existing software and hardware commercial solutions for shadow correction. At second, we have collected observer's opinions about quality of correction.

All existing shadow correction algorithms increase local contrast and signal level in shadows. This is their main goal and positive characteristic. However, some unwanted artifacts may appear as a result of image processing, and they are negatively perceived by the observer. Therefore it is necessary to form a list of those unwanted effects, create some test pattern for revealing and measuring those effects. Then the best algorithm will have the least disadvantages.

The following unwanted effects are revealed after processing by shadow correction solution:

- appearance of various artifacts, mainly halo near sharp edges of objects or boundaries of special shape;
- distortions of color, i.e. variation of color hue and/or saturation;
- noise amplification for whole tone range or only in the dark areas;
- over amplification of dark tones (black color becomes unpleasant dirty gray tint);
- over amplification of middle and light tones;
- posterization.

We proposed some test pattern (see fig. 7) for estimation of unwanted effects. Appearance of various artifacts and posterization effect was estimated visually. In particular, halo was estimated on steep edges of region 4. The horizontal gradient in region 3 is used for testing of posterization effect. The right half of test pattern is intended for measuring of color values and noise level in several regions. On the right half of test pattern the Gaussian noise is added. Parameters of correction for all tested solutions were selected so that in region 1 the result of correction was approximately identical. Average standard deviation for R, G, B channels for region 1 indicates noise level. For estimations of color invariance and absence of color distortions we measured hue and saturation for region 2. Brightness in region 5 is very low (almost black color). It is presumed that this region should not become black as a result of correction. Region 6 is used for measuring of middle tones amplification. Presumable, this region should not change its brightness badly.

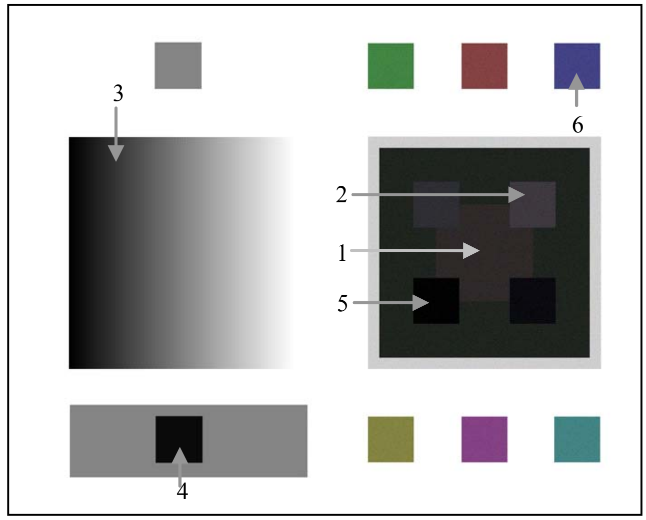


Figure 7: Test pattern for evaluation results of shadow enhancement approaches.

Following table enumerates several software applications aimed at shadow correction that were used for comparisons.

#	Software	Comments
1	Adobe Photoshop CS2 www.adobe.com	Shadow/Highlight menu item
2	Kodak Digital SHO professional 2.0 www.asf.com	Plug-in for Photoshop by Austin Development Center Eastman Kodak Company
3	Chroma Shadow Control 1.3 www.chromasoftware.com	Plug-in for Photoshop for shadow enhancement
4	FixerLabs Shadow Fixer 1.1.7 www.fixerlabs.com	Plug-in for Photoshop for shadow enhancement
5	IntrigueTek ShadowIlluminator www.intrigueplugins.com	Plug-in for Photoshop for shadow enhancement [10]
6	Nikon Capture 4.2 http://nikonimaging.com	There are two realization of the Nikon D-Lighting technology [9]
7	Akvis Enhancer http://akvis.com	Plug-in for Photoshop for Shadow/Highlight enhancement
8	TruView PhotoFlair 2.2 http://www.truview.com	Retinex in auto mode [7]

Measurement results are presented in diagrams in figures 8-11. Proposed method demonstrates negligible increase of noise level as a result of correction in comparison with original image. Other methods amplify noise more significantly. All considered methods insignificantly modify hue, but some of them greatly influence saturation. Adobe, Chroma, IntrigueTek result in modest desaturation, FixerLabs results in noticeable desaturation, and PhotoFlair results in noticeable oversaturation. Proposed method does not influence extremely dark tones. Other methods lighten these tones. Chroma and FixerLabs demonstrates unacceptable results.

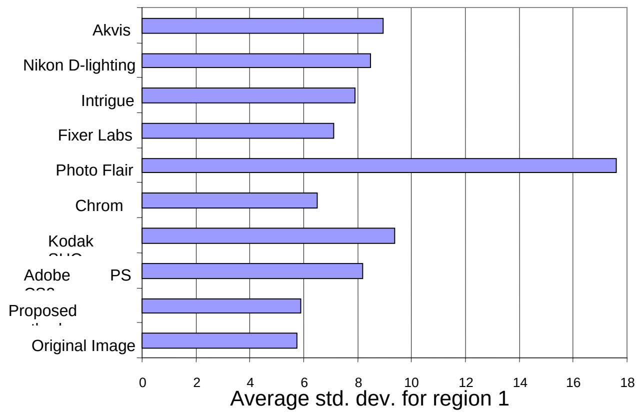


Figure 8: Comparison of noise level.

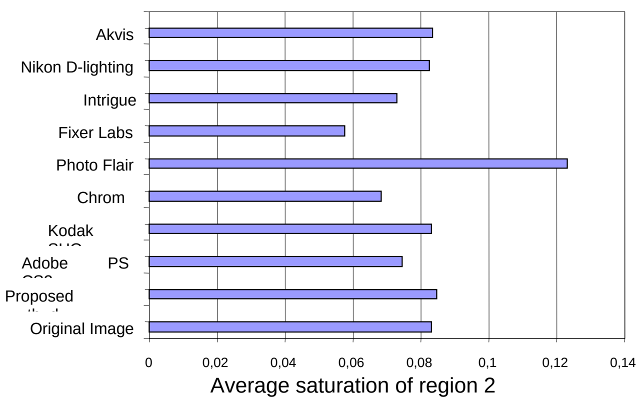


Figure 9: Comparison of saturation invariance.

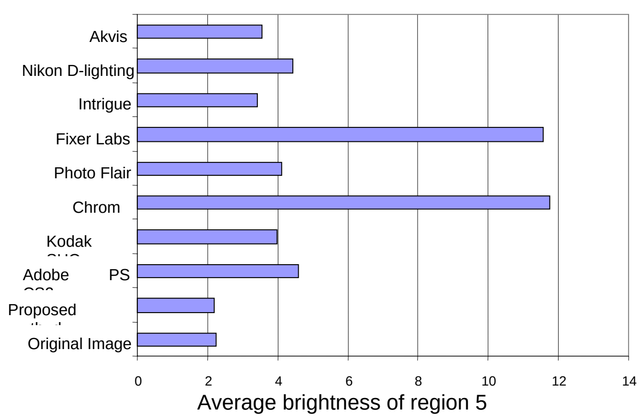


Figure 10: Comparison of amplification of extremely dark tones.

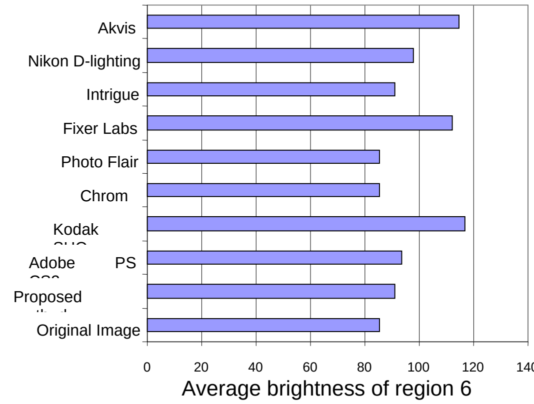


Figure 11: Comparison of amplification of middle tones.

Proposed method insignificantly lightens middle tones. Kodak, FixerLabs and Akvis amplify middle tones by 15-20%. All considered methods (except IntrigueTek ShadowIlluminator) result in some posterization effect. Proposed method does not lead to noticeable halo. Halo appears near sharp edges after application of Adobe, Nikon D-lighting HQ, Photo Flair. Figure 12 demonstrates advantages of the proposed method over Adobe Photoshop Shadow/Highlight tool: (a) result of Photoshop Shadow/Highlight, (b) initial photo, (c) enhanced photo by proposal method, (d) plot of brightness profiles along line segments *AB*. Adobe Photoshop Shadow/Highlight produce strong halo-effect, in the proposed method halo-effect is absent.

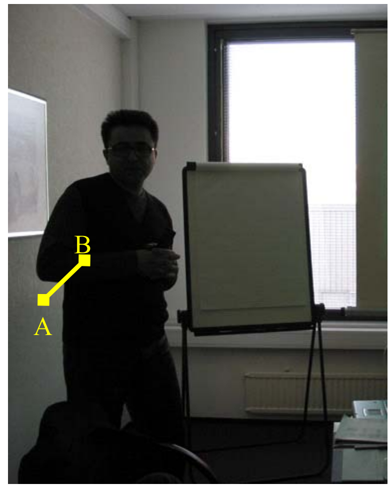
As it was mentioned earlier HDR compression methods also can be used for correction of LDR photos damaged by backlighting. However these methods usually lead to deterioration of highlights. Figure 13 demonstrates Comparison between proposed method and gradient domain High Dynamic Range compression [13]: a) - source image, b) – result of proposed method, c) – result of Gradient Domain HDR compression. Source image of Notre Dame de Paris and result [13] are available at www.cs.huji.ac.il/~danix/hdr/. Gradient domain HDR compression visualizes dark areas very well but damages light areas. Sky appears to be darker and desaturated. Details of the roof of Notre Dame became less distinguishable. Proposed method lightened dark tones slightly weaker but did not modify highlight tones. In addition theoretically proposed method is far quicker.

For estimation of the quality of processing from consumer point of view we corrected 5 photos damaged by backlighting and printed original and enhanced photos. The opinions survey among 28 observers was done. Each interviewee selected original photo or enhanced photo or both simultaneously as more pleasant one. The 90% of the observers have selected enhanced photos as more pleasant.

6. CONCLUSION

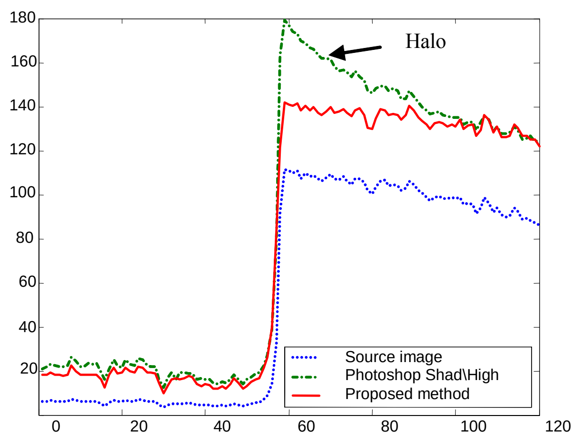
A lot of amateur photos are damaged by various exposure defects in particular backlighting. Image enhancement procedures are needed during printing and photofinishing for making photos more pleasant for observers. Last years the researchers pay attention for local contrast correction especially in shadows. However the existing solutions have some essential drawbacks.

a)



b)

c)



d)

Figure 12: Comparison result of proposed method with Adobe Photoshop Shadow/Highlight.

a)

b)

c)

Figure 13: Comparison result of proposed method with Gradient Domain High Dynamic Range compression.

The adaptive method of enhancement of color photos with the given exposure problems is proposed. The method consists of noise suppression using bilateral filter, global contrast adjustment and local shadow correction. The algorithm of shadow correction is performed for brightness and based on alpha-blending of brightness of the initial image and estimations of reflectance. For obtaining reflectance estimation a simplified illumination model is used. The luminance is estimated using recursive separable bilateral filter. Reflectance is estimated using heuristic functions of ratio between brightness of the initial image and estimation of luminance. Some sharpening occurs during correction.

The method is described in Russian patent application [19]. The optimized version of the proposed method was implemented in Samsung printing and scanning software utilities and was embedded into firmware of Samsung dye-sublimation compact photoprinters.

Present embodiment is fully competitive with existing solutions and correction results are positively estimated by observers.

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