Multimed Tools Appl (2017) 76:15027–15048
DOI 10.1007/s11042-017-4453-z

A photographic negative imaging inspired method for low illumination night-time image enhancement

Zhenghao Shi[1] **· Meimei Zhu**[1] **· Bin Guo**[2] **·**
Minghua Zhao[1]

Received: 17 November 2016 / Revised: 26 January 2017 / Accepted: 27 January 2017 /
Published online: 16 February 2017

Abstract Images captured in low illumination conditions usually suffer from a poor visibility which has an important affect on the performance of computer vision systems. Thereby low illumination image enhancement is critical for image-related applications. In this paper, we proposed a photographic negative imaging inspired method for enhancing the images taken under low illumination environments. It consists of three basic components. First, the input night-time image is reversed to obtain its corresponding negative image (which is comparable with the latent image of a photographic film). Second, a rectification on the negative image is performed (Which is comparable with the chemical development in the process of film processing) by using an image dehazing method. This operation is inspired by the observation that the negative image looks like a hazed image and thereby it can be enhanced using a dehazing method. Third, the rectified negative image is reversed to obtain the final enhanced image (Which is comparable with the operation of fixing in the later stage of film processing.). Experiments over a large quantity of low contrast night-time images show that the proposed method is effective for enhancing low illumination images. Compared with six state-of-the-art image enhancement methods, the proposed method is superior to them in both enhancing image quality and decreasing time cost.

Keywords Low illumination night-time image · Image enhancement · Negative image · Dark channel prior

✉ Zhenghao Shi
ylshi@xaut.edu.cn

[1] School of Computer Science and Engineering, Xi'an University of Technology, Xi'an 710048, China

[2] School of Computer, Northwestern Polytechnical University, Xi'an 710072, China

1 Introduction

Low illumination night-time image enhancement is critical for a wide range of image-related outdoor applications, such as surveillance systems, intelligent vehicles, satellite imaging, and outdoor object recognition systems [6]. Images captured in night-time under low illumination conditions are usually seriously degraded due to insufficient light, such as low contrast, distorted colors and unclear details etc., and seriously affect the performance of image-related outdoor systems [24]. It is obvious that low illumination night-time image enhancement is highly desirable to ensure the reliable of outdoor vision systems.

Inspired by the photographic negative imaging techniques, a novel low illumination image enhancement method base on negative image is proposed in this paper. The novel contributions of the method are summarized as follows:

(1) Negative night time images can be conserved as hazed images
(2) Low illumination image enhancement can be realized by rectification its corresponding negative images using a image dehazing method.

The rest of this paper is organized as follows. Section 2 discusses related works. Section 3 describes the basic process of photographic developing, presents the proposed method in detail. Section 4 gives the implementation of our experiments and reports the results. A discussion on the proposed method is given in Section 5. Conclusions are provided in Section 6.

2 Related works

Considerable work to low illumination image enhancement has been done in recent years [5–8, 11, 12, 14–17, 19, 21, 23–25, 27]. In [5, 17, 21, 25], multiple images of the same scene under different conditions are used for low illumination night-time image enhancement. The basic idea of such methods is to exploit the advantages of multiple images by using image fusion techniques. For example, in [5, 25], images taken at different times are combined to enhance night-time images. In [17, 21], infrared images are fused with visible images for the enhancement of night-time images. Though this kind of method can enhance low illumination night-time image effectively, it requires multiple images that are in exact correspondence which is not always available.

Compared to using multiple images for image enhancement, image enhancement based on single image has received increasing attention recently [16, 23, 27]. In [16], improved histogram equalization is proposed for contrast enhancement. In [27], a global brightness and local contrast adaptive enhancement method is proposed. In [23], the homomorphic filtering is employed to enhance illuminating degraded images. In [1–3, 7–15, 18, 19, 22, 26], various Retinex-based methods have been proposed for low illumination image enhancement. The Retinex [14] is an effective theory proposed by Edwin Land to achieve color constancy and dynamic range compression by simulating Human Visual System (HVS). In [15], the center/surround retinex was proposed, which has the characteristics of fast computation and less parameters. In [12], an improved center/surround retinex, termed as the single scale retinex (SSR), was proposed. Compared with traditional center surrounding algorithms, SSR has obvious advantages such as higher operation speed and clearer physical meaning.

However, SSR has a drawback that for a small scale it had compression in dynamic range and for a large scale tonal rendition occurs. Researchers in [11] proposed multi-scale retinex (MSR) method, which are cable of accomplish color rendition and dynamic range compression at the same time. Though, it showed color distortion when applied to RGB images. [7, 8] focus on better color correction for retinex algorithm. The method proposed in [19] tried to improve MSR by reducing halo artifacts and graying effect. In [18], the relationship between retinex and image compression was investigated. In [9], MSR was improved with respect to weights of different scales of retinex. In [10, 22], improved methods to accelerate MSR were discussed. In [13], to minimize data loss, and adapts MSR to night-time images by merging results from sigmoid-MSR with original images, the logarithm function in MSR was replaced with a customized sigmoid function. A new statistical enhancement method based on Retinex was proposed by analyzes the transformation relationship between the night-time image and illumination image by the algorithm of Michael Elad and MSRCR algorithm. In [1], to overcome the problems of halo, grey and noise amplification, a Gaussian weighted bilateral filtering and Retinex based image enhancement algorithm was proposed. Though a lot of efforts have been done on the improvement of MSR, as aforementioned, color distortion is still appearing and the algorithm complexity is still high.

3 The proposed method

3.1 The basic process of photographic developing

Many people who have used film cameras know that the photographic elements contain a blue - sensitive hydrophilic colloid silver halide emulsion layer. The emulsion is a substance that is used to make photographic film sensitive to light. Once a photographic film is exposed, that is when light strikes the emulsion, a change occurs in the microscopic crystals of silver-halide, and as a result a latent image, an invisible image, as shown in Fig. 1(a), is generated immediately. To obtain a visible image, developing of the latent image has to be done. After photographic developing, the negative image of the latent image is generated, namely developed film. When developed, the microscopic crystals of silver-halide of the latent image form crystals of black metallic silver. As a result, the areas of the frame that are stuck by light are transformed into dark black metallic-silver areas on the negative. If there is a heavy deposit, the area is dense (black), as shown in Fig. 1(b). By reduction, a reversal process of the negative image, a positive image film can be obtained, as shown in Fig. 1(c). The process of reduction consists of converting part of the silver image into a compound which can be dissolved. Since the negative is the reverse of the final image in the print, the dense black area in the negative becomes white in the print.

The basic process of photographic developing enhancement lies in getting appropriate information from the negative and its basic idea was obtained based on two discoveries. The first one is that the densities can be adjusted through applying more or less development to the negative image. The second one is that the development modification has its primary effect on the high values. So if a paper is placed in a photographic developer, a positive image of the original object will appear on the paper.

Based on the observation of the photographic developing, we find that the contrast of images can be enlarged and their saturation can also be increased when their negative images (or reverse images) are rectified.

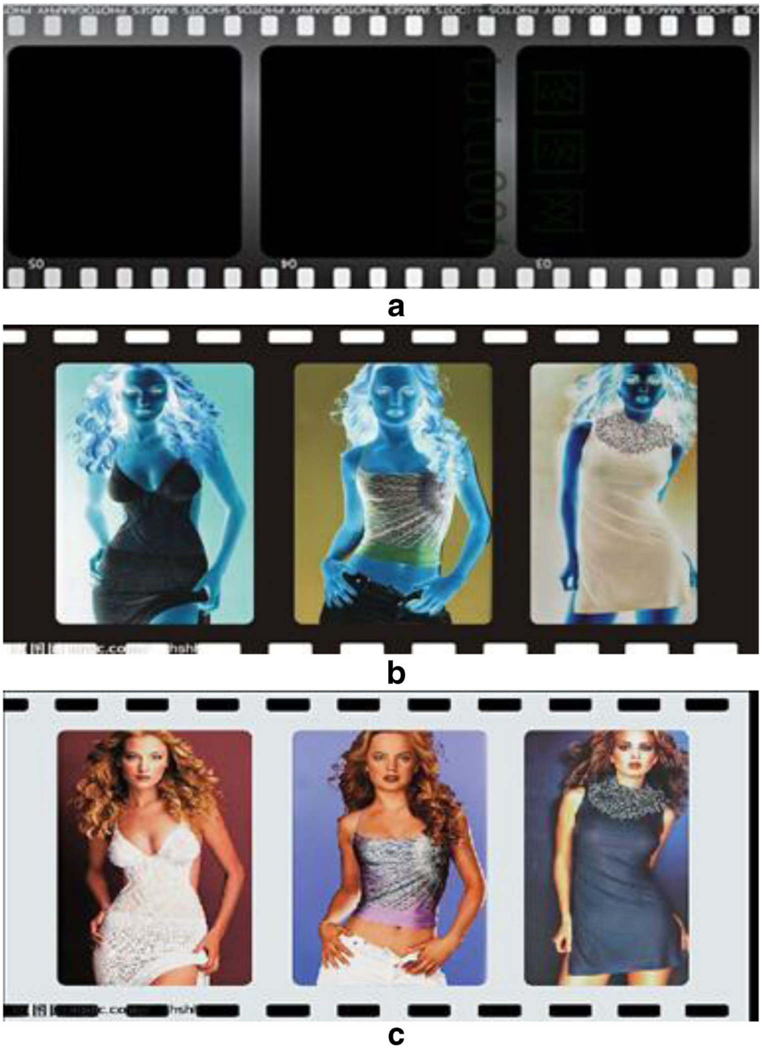


Fig. 1 Photographic image: from a latent image to positive visible image. **a** Latent images; **b** Negative images; **c** Photographic images (positive visible image)

3.2 Low night image enhancement based on the rectification of negative image

Inspired by aforementioned photographic developing enhancement, a simple night-time enhancement method based on negative images rectification is proposed in this section. Figure 2 shows the basic ideas of the proposed method. It consists of three basic computation steps. Firstly, the input night-time image is reversed to obtain its corresponding negative image; Then a rectification on the negative image is done by using Dark channel prior based image enhancement technique, this operation comes from such an observation that the negative image looks like a hazed image; finally, the enhanced negative image is reversed to obtain the final enhanced night-time image. Details of the method for the negative image rectification are described as fellows.

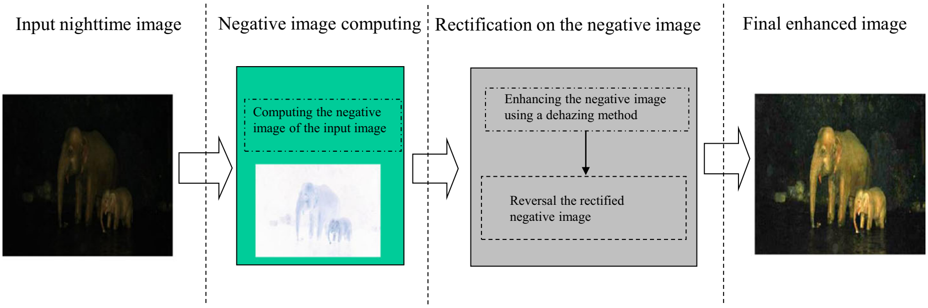


Fig. 2 Low illumination image enhancement method based on negative images rectification

An observations on large amounts of the night-time negative images show that the night-time negative images have such characteristics as blurring image with partial white colors, which make the negative image look like a hazed image. Based on such an observation, we can take the night-time negative image as a hazed image, and thus we can express the night-time negative image using the hazed image optical model, which is described as Eq. (1):

$$t(x) = 1 - \omega \frac{I^{\text{dark}}(x)}{A} \tag{1}$$

where x is the location of a pixel, I(x) is the night-time negative image, J(x) is the rectified negative image, A is the global atmospheric light for the negative image, and t(x) is the transmission coefficient which represents the ability that light interactions with the atmosphere. According to Dark prior proposed by He [3], t(x) can be obtained with the following formulation:

$$t(x) = 1 - \omega \frac{I^{\text{dark}}(x)}{A} \tag{2}$$

where $I^{dark}(x)$ is called the dark channel of the night-time negative image I(x), $I^{dark}(x)$ is a constant, which is used to describe the haze concentration, usually $0 < I^{dark}(x) < 1$. The value of $I^{dark}(x)$ is assigned according to the Histogram gray statistics of the night-time negative image. $I^{dark}(x)$ is obtained using the Minimum filter method described as bellows:

$$I^{\text{dark}}(x) = \min_{c \in \{r,g,b\}} \left(\min_{y \in \Omega(x)} \left(I^c(\mathrm{x}) \right) \right) \tag{3}$$

where I^c is a color channel of image I, $\Omega(x)$ is a local patch centered at x. According to [3], we know that for a haze free image, $I^{\text{dark}}(x) \to 0$; For a hazed image, $I^{\text{dark}}(x)$ is no long black.

To estimate the value of A, a two stage selection method is employed in this work. First we pick the top 0.1% brightest pixels in the dark channel of the night-time negative image I(x), and then the pixel with highest intensity is selected as the value of A.

Once the transmission *t(x)* and atmospheric light *A* are estimated, the rectified night-time negative image can be obtained by simple inversion of Eq. (4):

$$J(x) = \frac{I(x) - A}{t(x)} + A \tag{4}$$

In summary, the proposed method is shown as follows:

Input: Low illumination night-time image I _input

The patch size Ω

The initial transmission coefficient t_0

The threshold value T of the Histogram of the night-time negative image.

Output: The enhanced night-time high illumination image I_enhanced

----

Step 1: Compute the corresponding negative image of the input night-time image with:

$$I = 255 - I\_input \tag{5}$$

Step 2: Rectify the negative image of the input night-time image based on Dark prior

1) Compute the dark channel $I^{dark}(x)$ of the night-time negative image I(x) according to Equation (3);
2) Compute the gray histogram of the dark channel $I^{dark}(x)$, and count the percent of pixels whose intensity value is smaller that the threshold value T, under_T;
3) Estimate the value of A: First, we pick the top 0.1 percent brightest pixels in the dark channel of the night-time negative image I(x). And then the pixel with highest intensity is selected as the value of A;
4) Compute parameter t(x) according to equation (2);
5) Compute the rectified negative image J.

Step 3: Compute the final enhanced night-time image with:

$$I\_enhanced = 255 - J \tag{6}$$

3.3 Time complexity

The time complexities of aforementioned methods are analyzed for the image size M *N. In the case of the traditional histogram equalization method, the computation of the histogram requires O(MN) time. Calculating the mapping function from the histogram requires O(L) time, where L denotes the discrete level of the input image. Finally, the enhanced image is obtained using the mapping function in O(MN) time. Hence, the total time complexity of the traditional histogram equalization method is O(2MN + L).

In the case of homomorphic filtering method, the total time complexity of the method is determined by the computation of illumination image. Due to the computation of illumination image requires O(MN) time. Hence, the total time complexity of homomorphic filtering method is O(MN).

In the case of SSR method, the total time complexity of the method is determined by the computation of illumination image. Due to the computation of illumination image only uses a single scale image and enhances the contrast of the under-exposed region to extend the dynamic range, which requires O(MN) time. Hence, the total time complexity of SSR is O(MN) too.

In the case of the traditional MSR method, the computation of illumination image in a single scale requires O(MN) time. For the computation of all three multiple scale, the total time complexity is O(3MN). Hence, the total time complexity of the traditional MSR is O(3MN).

In the case of the MSRCR method, the computation of illumination image of single color channel requires O(MN) time. For the computation of all three color channel, the total time complexity is O(3MN). Calculating the color correction factor requires O(MN) time. Hence, the total time complexity of the MSRCR is O(4MN).

In the case of bilateral based MSR method, the method estimates the light source and reflectance in each color channel using the bilateral filter, whereas the computation of bilateral for the computation of illumination image of single color channel requires O(MN) time. For the computation of illumination image of single color channel requires $O((MN)^2)$ time. For the computation of all three color channel, the total time complexity is $O(3(MN)^2)$. Hence, the total time complexity of bilateral based MSR is $O(3(MN)^2)$, which result in the longest computation time.

In the case of proposed method, the total time complexity of the method is determined by the computation of negative image correction where the dark channel prior based method is employed. The computation of dark channel prior based correction requires O(3MN) time. Hence, the total time complexity of the proposed method is O(3MN).

4 Experiments

To evaluate the proposed method, extensive tests have been done using Matlab R2010 with 2200 night-time low illumination color images on a PC with Intel(R) Core (TM) i5-3230 M CPU @ 2.60 GHz with 8 GB RAM.

All images used in this experiment come from the image set built by our group, and the image set consists of 1200 images, a little part of them is taken by our authors, most of them, about 1000 images, are come from the Internet.

For the sake of comparison, six state-of-the-art methods, including Histogram equalization [16], Homomorphic filtering [23], single scale retinex (SSR) [12], multi-scale retinex (MSR) [11], Multi-Scale Retinex with Color Restoration (MSRCR) [7] and Bilateral based Multi-Scale Retinex [2], are chosen as the competing approaches.

The parameters used in our experiments for this proposed method are set as fellows: the patch size Ω is assigned as 15 by 15 refer to [3]; the value of parameter ω is assigned as 0.65, initial transmission coefficient $I^{dark}(x)$ is set as 0; The threshold T is set as 50, which is come from experience prior. under_T is the percent of pixels whose intensity value is smaller that the threshold value T, which is give by computing the gray histogram of the dark channel of negative image.

The parameters of related algorithms are set as: the spatial extents of the Gaussian function are 30, 80, and 250, respectively. And all other parameters are consistent with the original papers. [2, 7, 11, 12, 16, 23].

For objective evaluating the performance of aforementioned method in enhancing low illumination night-time images, four indexes are employed for quantitative analysis in this work, including the pixel mean, standard deviation, average gradient, and information entropy. The definition of these indexes is described as bellows.

(1) The pixel mean is the average gray value of all image pixels of one image, as defined in Eq. (7), which shows the level of the image brightness and darkness. A higher value represents a higher contrast. In general, the greater contrast corresponds to the higher visibility.

$$I_m = \frac{\sum_{j=1}^{N}\sum_{i=1}^{M} I(i,j)}{M \times N} \tag{7}$$

where I(i,j) is the gray value of pixel (i,j), M and N are the length and width, respectively. M × N is the total number of pixels. And I_m is the pixel mean. Image standard deviation

(2) Image standard deviation shows the level of image contrast, as defined in eq. (8). The bigger the image standard deviation value is, the greater the image contrast is.

$$\sigma_g = \sqrt{\sum_{j=1}^{N}\sum_{i=1}^{M} \left(I(i,j) - I_m\right) \Big/ M \times N} \tag{8}$$

where I(i,j) is the gray value of pixel (i,j), M and N are the length and width, respectively. M × N is the total number of pixels. And I_m is the pixel mean. Image standard deviation

(3) The average gradient of the image is an important index for measuring the contrast expression ability of image details, which indexes the image clarity. A larger value signifies a sharper image as perceived by the viewer. The definition of the average gradient is show in eq. (9), where I(i,j) is the gray value of pixel (i,j), M and N are the length and width, respectively.

$$\overline{g} = \frac{1}{(M-1)(N-1)} \times \sum_{i=1}^{M-1}\sum_{j=1}^{N-1} \sqrt{\frac{\left(I(i,j) - I(i+1,j)\right)^2 + \left(I(i,j) - I(i,j+1)\right)^2}{2}} \tag{9}$$

(4) Information entropy is a statistical measure of image information randomness. Higher entropy value generally indicates more details. Equation (9) gives the definition of the information entropy of an image, where p(g) is the distribution probability of gray level g, and L is the number of gray levels.

$$EN = -\sum_{g-0}^{L-1} p(g)\log_2 p(g) \tag{10}$$

4.1 Qualitative analysis

Figures 3 and 4 show part experimental results on low illumination night-time images, respectively. Of which figure (a) is the input original image, figure (b) is the final enhanced image with the proposed method in this work.

Fig. 3 Low illumination night-time image enhancement using the proposed method in this work. **a** Input images; **b**enhanced images

It can be seen from Fig. 3 that the contrast of the original input image (Fig. 3a) is very lower, almost all image details are submerged by dark (or black), the color is non-vivid, the scene is difficult to distinguish. Whereas the contrast and details of the image enhanced using the proposed method in this work are increased significantly where the color is vivid, and has a well visual perception. The proposed method has a similar significantly improvement effect on people image captured in poor illumination conditions, as shown in Fig. 4. It can be seen that the people in the enhanced image (Fig. 4b) is clearer to see where the color is vivid and the contrast of the image is significantly.

Figure 5, 6, 7, 8, 9, 10, and 11 show part comparison of the proposed method in this work with Histogram equalization [16], Homomorphic filtering [23], single scale retinex (SSR) [12], multi-scale retinex (MSR) [11], Multi-Scale Retinex with Color Restoration (MSRCR) [7] and Bilateral based Multi-Scale Retinex [2] on low illumination night-time images, where figure (a) is the input original image, figure (b) and (c) are the enhanced image with aforementioned different methods.

Fig. 4 Low illumination night-time image enhancement using the proposed method in this work. **a** Input images; **b** enhanced images

It can be seen from Fig. 5 that after processed with histogram equalization the brightness of the image is enhanced, many invisible image details are also visible. However, image noises are also enhanced, and serious color distortion also occurs, and which causes an unnatural look and visual artifacts of the processed image. Compared with histogram equalization, the color of the enhanced image with the proposed method in this work is naturally, there no color distortion occurs and noise enhanced (no color distortion and noise increased), where image details are well restored.

It can be seen from Fig. 6 that the enhanced image with the proposed method in this work appears more appealing to a viewer with a better color tone and higher contrast with more visible details in respect to that with homomorphic filtering method, which shows that the homomorphic filtering method has little effect on low illumination night-time image.

It can be seen from Fig. 8 that after processed with multi-scale retinex the scene details are restored, many invisible details in input image become visible, and the brightness of the whole image is enhanced. However, image noises are exaggerated, which leads a serious color distortion, and causes an unnatural look and visual artifacts of the processed image.

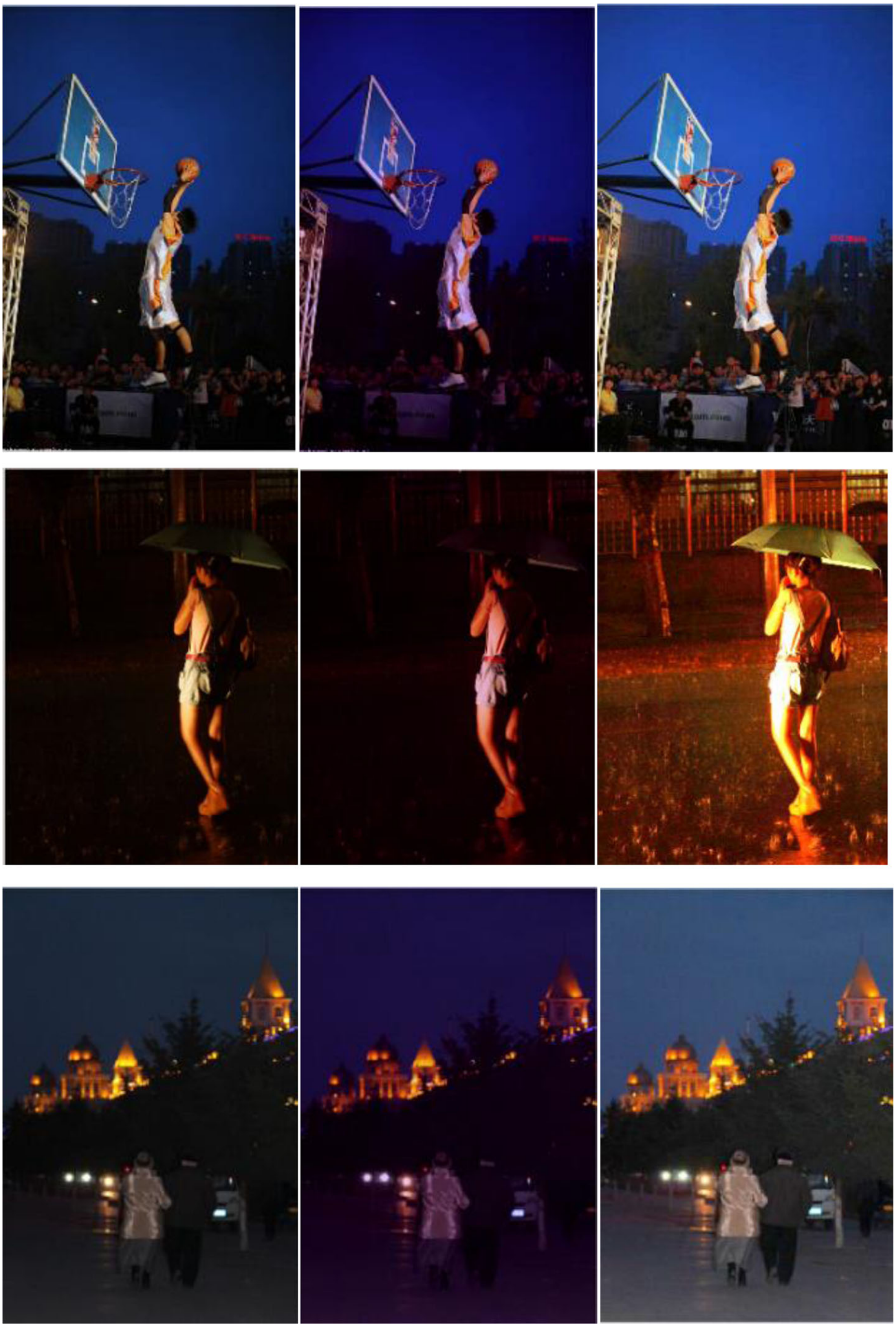
Fig. 5 Comparison of the proposed method in this work with Histogram equalization [16]. **a** Input images; **b** enhanced images with Histogram equalization [16]; **c** enhanced image with the proposed method in this work

Figure 7 shows comparison of the proposed method with single scale retinex (SSR) [12]. From Fig. 7, it can be seen that the enhanced images with the proposed method (Fig. 7a) highlight details and is more bright, lively and natural in respect to that with SSR method (Fig. 7b) where there occurs obvious Halo artifacts, noise are more intensive and highlighted areas flooded with white, and the whole image tends to grayish.

Figure 9 shows comparison of the proposed method with Multi-Scale Retinex with Color Restoration (MSRCR) [7]. From Fig. 9, it can be seen that MSRCR algorithm gives a good color restoration, the color of the enhanced image is vivid, and the contrast and illumination of dark regions are also enhanced, invisible details in these dark regions become visible. However, the contrast of brighter regions degraded, and details looks blur.

Figure 10 shows comparison of the proposed method with Bilateral based Multi-Scale Retinex [2]. As it can be seen that there are obvious artifacts in the edge of regions of the enhanced image with Bilateral based Multi-Scale Retinex, such as in the border of trees and the sky, at the edge of tree shape and at the outline border of the yang man in the image where intensity abrupt changed, as shown in Fig. 10b). Whereas these artifacts are obvious eliminated in the enhanced image with the proposed method, where details are highlighted, the image is brighter, the color looks more lively and natural.

Figure 11 and Fig. 12 show an overview comparison of the proposed method in this work(figure (h)) with Histogram equalization [16](figure (b)), Homomorphic filtering [23] (figure (c)), single scale retinex (SSR) [12] (figure (d)), multi-scale retinex (MSR) [11] (figure (e)), Multi-Scale Retinex with Color Restoration (MSRCR) [7] (figure (g)) and Bilateral based Multi-Scale Retinex [2] on low



a b c

Fig. 6 Comparison of the proposed method in this work with homomorphic filtering [23]. **a** Input images; **b** enhanced images with homomorphic filtering [23]; **c** enhanced image with the proposed method in this work

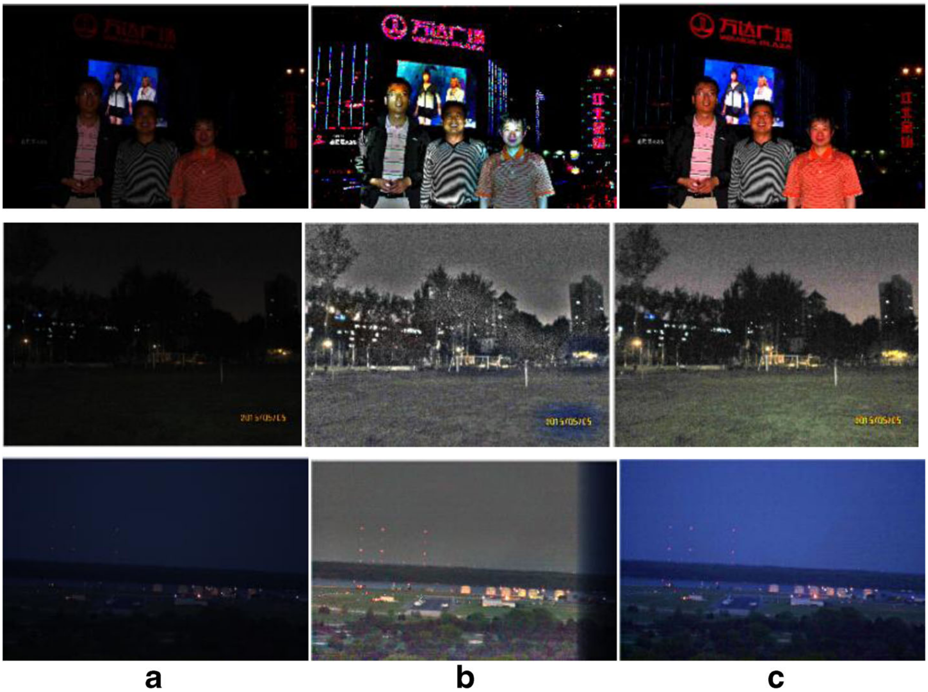


Fig. 7 Comparison of the proposed method in this work with single scale retinex (SSR) [12]. **a** Input images; **b** enhanced images with single scale retinex (SSR) [12]; **c** enhanced image with the proposed method in this work

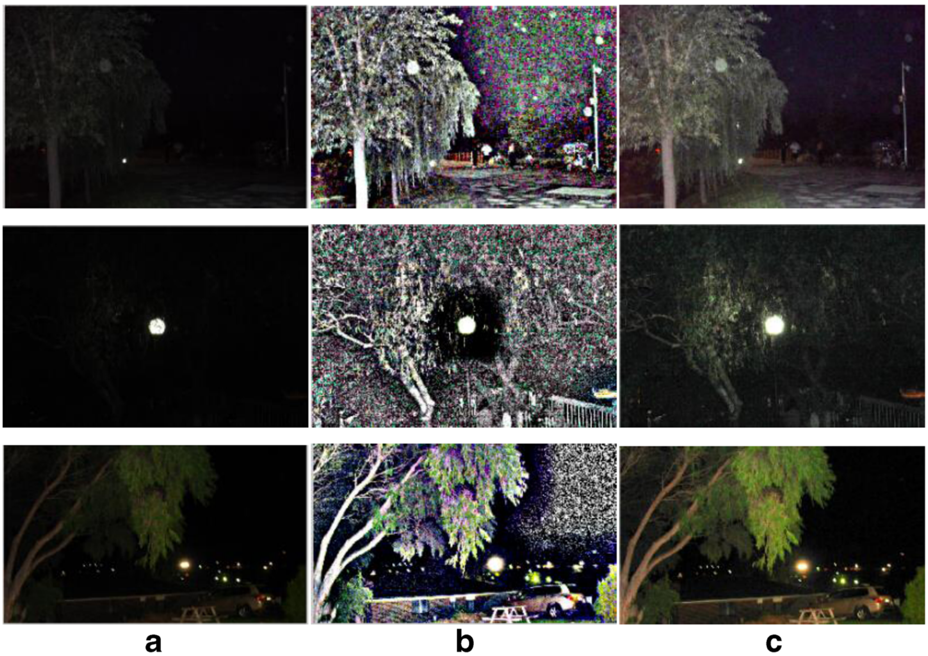


Fig. 8 Comparison of the proposed method in this work with multi-scale retinex (MSR) [11]. **a** Input images; **b** enhanced images with multi-scale retinex (MSR) [11]; **c** enhanced image with the proposed method in this work

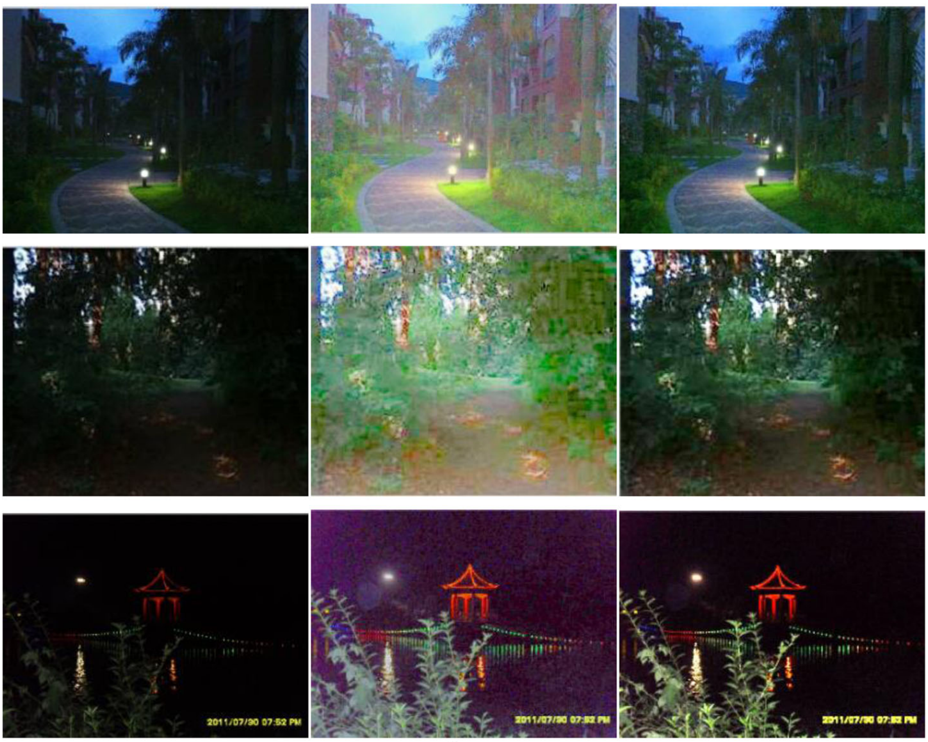

a b c

Fig. 9 Comparison of the proposed method in this work with Multi-Scale Retinex with Color Restoration (MSRCR) [7]. **a** Input images; **b** enhanced images with Multi-Scale Retinex with Color Restoration (MSRCR) [7]; **c** enhanced image with the proposed method in this work

illumination night-time images(figure (g)). It can be seen from Fig. 11 and Fig. 12 the contrast of all input images (Fig. 11a) and Fig. 12a are very lower and the color are non-vivid. All aforementioned methods have significantly nhanced the input images. In respect to the input images, the illuminations of all images enhanced with aforementioned methods have improved in different level. Invisible details in the dark regions of the input image are all almost visible in the enhanced images. However, it can be seen that images enhanced with Histogram equalization (figure (b))and homomorphic filtering(figure (c)) , due to abrupt changes in intensity, viewing artifacts occur where several regions are too dark or too bright such that feature details are lost, and the images look unnatural. Whereas the performances of all Retinex based methods are obvious superior to that of Histogram equalization and Homomorphic filtering. Of which SSR (figure (d)), MSR (figure (e)) and MSRCR (figure (f)) have obvious effect on improving the brightness of the images, whereas MSR exaggerate image noises, and causes a serious color distortion. Compared with the enhanced image with MSR (figure (e)), the color of the enhanced with MSRCR (figure (g)) is corrected, but the whole images look more bright, and unnaturally. Compared with aforementioned methods, the performance of this work (figure (h)) in illumination improvement is not as good as that of MSRCR, it is closer to that of Bilateral based

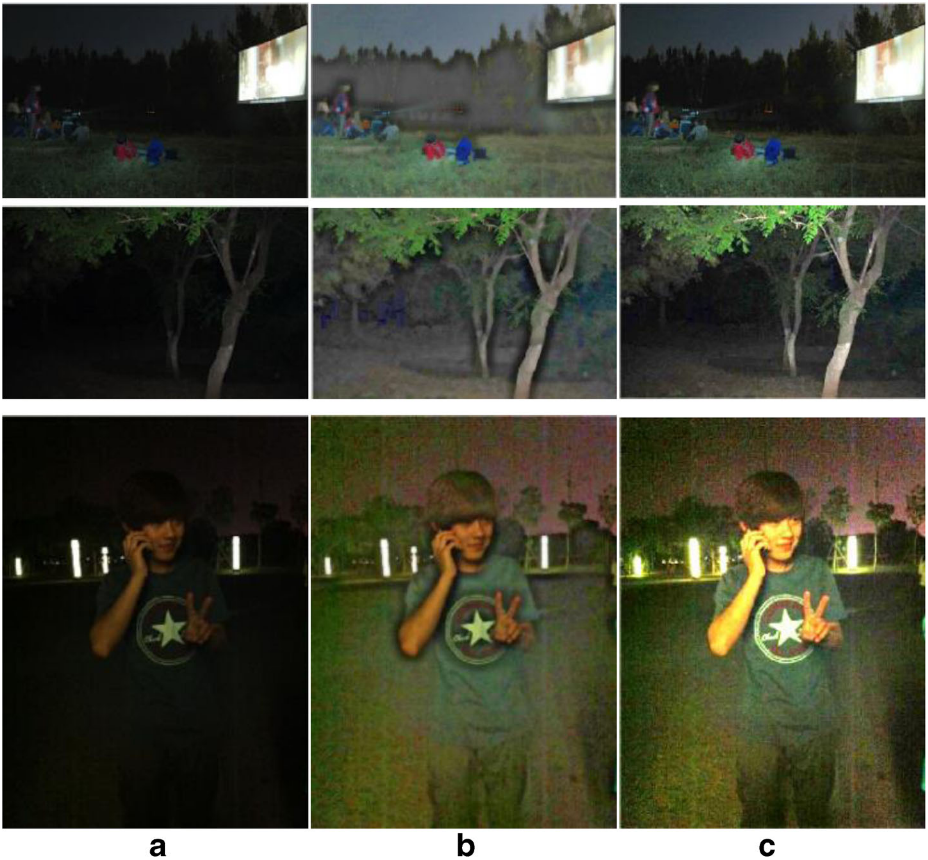


Fig. 10 Comparison of the proposed method in this work with Bilateral based Multi-Scale Retinex [2]. **a** Input images; **b** enhanced images with Bilateral based Multi-Scale Retinex [2]; **c** enhanced image with the proposed method in this work

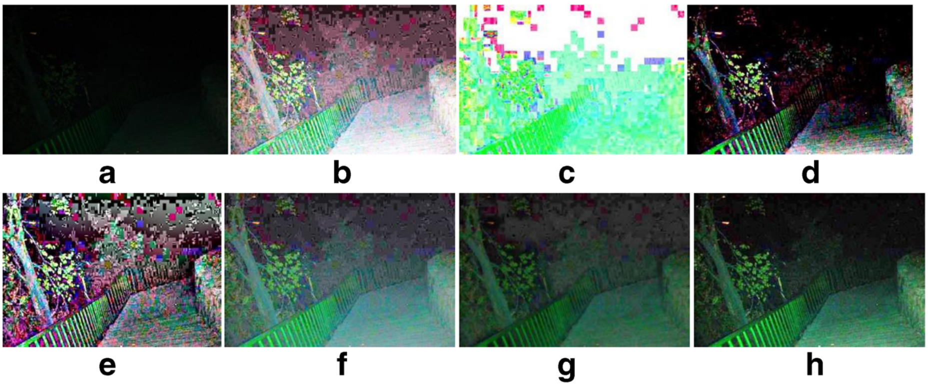


Fig. 11 Comparison of the proposed method with different aforementioned method. **a** input image; **b** enhanced image with Histogram equalization [16]; **c** enhanced image with homomorphic filtering; **d** enhanced image with single scale retinex (SSR) [12]; **e** enhanced image with multi-scale retinex (MSR) [11]; **f** enhanced image with Multi-Scale Retinex with Color Restoration (MSRCR) [7]; **g** enhanced image with Bilateral based Multi-Scale Retinex [2]; **h** enhanced image with the proposed method in this work

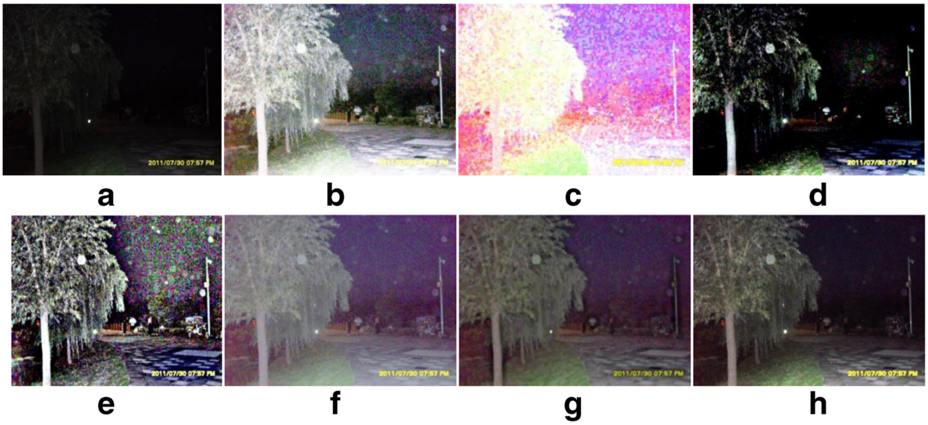


Fig. 12 Comparison of the proposed method with different aforementioned method. **a** input image; **b** enhanced image with Histogram equalization [16]; **c** enhanced image with homomorphic filtering; **d** enhanced image with single scale retinex (SSR) [12]; **e** enhanced image with multi-scale retinex (MSR) [11]; **f** enhanced image with Multi-Scale Retinex with Color Restoration (MSRCR) [7]; **g** enhanced image with Bilateral based Multi-Scale Retinex [2]; **h** enhanced image with the proposed method in this work

Multi-Scale Retinex. However, the brightness of the whole image enhanced with the proposed method is more natural in visional. In restoring the invisible details in dark regions, the performance of the proposed method is obvious superior to all other aforementioned methods, as shown in Fig. 11h) and Fig. 12h), both invisible details in dark regions and bright regions are well restored, which avoids details blur caused by over-enhancement. Halo artifacts are also obvious alleviated.

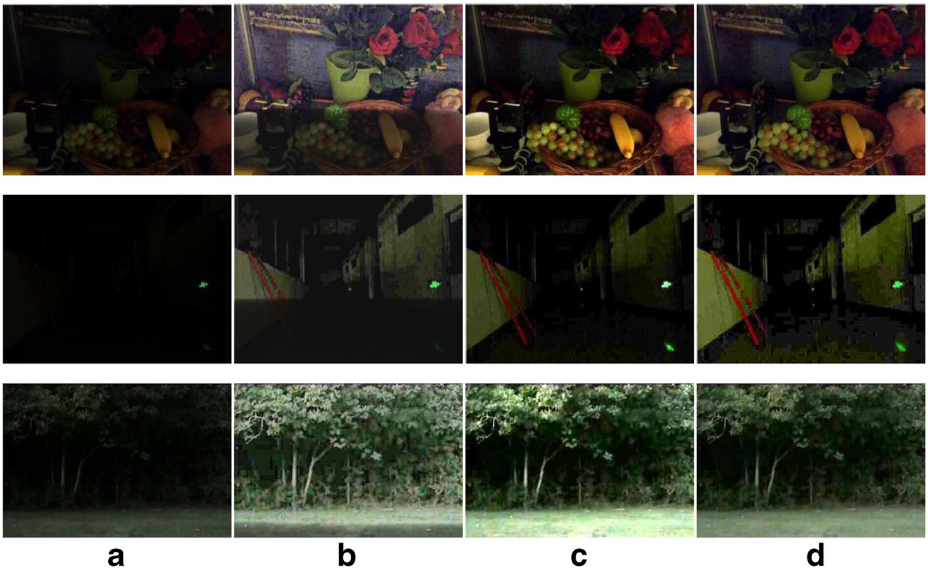


Fig. 13 Comparison of different dehazing algorithms for night time enhancement. (a) input image; (b) Tarel's method [20]; (c) He's method [4]; (d) He's method [3]

Fig. 14 Comparison of affection of different local patch size on night time enhancement. (a) input image; (b) 5 by 5; (c) 15 by 15; (d) 30 by 30

4.2 Quantitative analysis

Table 1 shows comparison of different measures for different aforementioned method, which related to Fig. 11. Table 2 shows comparison of different measures for different aforementioned method, which related to Fig. 12.

From Table 1 and Table 2, we can see that all aforementioned methods increase the mean, the standard deviation, the average gradient and the entropy of the image in a certain extent, which indicating that they improve the quality of the input image in a certain extent. Of which, homomorphic filtering has the most significant improvement on the mean, obviously superior to others. The mean with the proposed method is closer to that with bilateral based MSR. MSRCR has less improvement on standard deviation compared with other methods, which consistent with that in the subjective evaluation that the enhanced image with MSRCR is brighter with a lower contrast.

Table 3 and Table 4 show the average computation time of aforementioned method on Fig. 11 and Fig. 12, respectively. From Table 3 and Table 4, it can be seen that the computation time of the bilateral based multiple scale Retinex are 16,49 s and 43.42 s, respectively, which is the longest of all computation times, whereas the

Table 1 Comparison of different measures for different aforementioned method, which related to Fig. 11

	Mean	Deviation	Average gradient	Entropy
Input image	6.5097	6.1621	1.0451	4.0881
Histogram equalization	138.8943	65.7637	17.7240	7.8801
homomorphic filtering	201.0853	67.1079	10.8077	5.8179
SSR	35.3065	57.4582	13.6772	5.2901
MSR	96.6711	72.4170	31.4452	7.5830
MCSR	86.6023	40.5909	8.3718	7.2515
Bilateral based MSR	46.9525	22.4861	4.2899	6.4371
The proposed method	43.7074	37.2416	6.4561	6.7019

Table 2 Comparison of different measures for different aforementioned method, which related to Fig. 12

	Mean	Deviation	Average gradient	Entropy
Input image	14.8895	14.8397	2.3141	5.1277
Histogram equalization	132.7452	70.1816	13.0296	7.9730
Homomorphic filtering	218.6133	44.3629	6.5361	6.2010
SSR	27.5506	52.4336	10.6525	4.6998
MSR	90.8217	67.0649	28.5835	7.6164
MCSR	108.1579	32.1201	5.5535	7.0125
Bilateral based MSR	68.8368	24.6649	4.3606	6.6328
The proposed method	54.2570	36.1891	6.2997	6.9313

computation time of the SSR are 0.1745s and 0.3811 s, respectively, which is the shortest of all. The computation times of the proposed method are 0.5449 s and 1.3572 s, which is similar to that of MSR. Both of these two methods are close to real time computation.

5 Discussion

In this paper, we proposed an interesting method for night time image enhancement based on negative image rectification using image dehazing technique. To test whether other dehazing methods can obtain similar results, an experiment on comparison of using different dehazing methods for negative image rectification are given in this section. Figure 13 shows part experimental results. It is obvious seen that all dehazing algorithms can obtain similar results. This indexes that we treat the negative night time image as a hazed image, and use dehazing methods for negative image rectification is reasonable and effectively.

In our proposed method, we used the dark channel prior based dehazing technique for negative image rectification. Because the local patch is an important parameter for the computing of dark channel, so to evaluating how this parameter affect the quality of the results, an evaluation of the results using three different patch sizes is described in Fig. 14. The three different patch sizes is 5 by 5, 15 by 15, and 30 by 30, respectively. From Fig. 14, it is obvious seen that the local patch size has an important affection on the quality of enhanced image, the size is more small, more enhancement can be obtained. However, smaller local patch might make a little unnatural color of the enhanced image. In a weight of whole image quality, in this work, the local patch size is set as 15 by 15.

Table 3 The average computation time of different methods

Method	Computation time(s)
Histogram equalization	0.596501
Homomorphic filtering	0.215727
SSR	0.174555
MSR	0.539849
MCSR	0.876774
Bilateral based MSR	16.490765
The proposed method	0.544972

Table 4 The average computation time of different methods

Method	Computation time(s)
Histogram equalization	1.592930
Homomorphic filtering	0.701590
SSR	0.381120
MSR	1.142644
MCSR	2.076233
Bilateral based MSR	43.426683
The proposed method	1.357241

6 Conclusions

In this paper, a photographic negative imaging inspired method for night-time image enhancement is proposed. The core of the method is the operation of negative image correction using Dark channel prior based technique, which comes from such an observation that the negative image looks like a hazed image. We evaluated the performance of the proposed method in terms of qualitative analysis and quantitative analysis, the computation complexity of the proposed method is also analyzed. Experiments on a large quantity of low contrast night-time images revealed that the proposed method generated very high-quality enhancement images compared with the other state- of-the-art methods.

Acknowledgements This work was supported in part by a grant from the National Natural Science Foundation of China (No. 61202198, No.61401355, No. 41601353), a grant from the China Scholarship Council (No.201608610048), the Key Laboratory Foundation of Shaanxi Education Department (No.14JS072) and the Nature Science Foundation of Science Department of PeiLin count at Xi'an(GX1619). The authors gratefully acknowledge the helpful comments and suggestions of the reviewers.

References

1. Chang J, Bai J (2015) An image enhancement algorithm based on Gaussian weighted bilateral filtering and retinex theory. In Proceedings of the 8th International Congress on Image and Signal Processing, IEEE, pp 257–262
2. Elad M (2005) Retinex by two bilateral filters. In Scale Space and PDE Methods in Computer Vision (pp. 217–229). Springer Berlin Heidelberg
3. He K, Sun J, Tang X (2011) Single image haze removal using Dark Channel prior. IEEE Trans Pattern Anal Mach Intell 33(12):2341–2353
4. He K, Sun J, Tang X (2013) Guided Image Filtering. IEEE Trans Pattern Anal Mach Intell 35(6):1397–1409
5. Hogervorst MA, Toet A (2010) Fast natural color mapping for night-time imagery. Information Fusion 11(2):69–77
6. Huang SC, Yeh CH (2013) Image contrast enhancement for preserving mean brightness without losing image features. Eng Appl Artif Intell 26(s 5–6):1487–1492
7. Jang IS, Park KH, Ha YH (2009) Color correction by estimation of dominant chromaticity in multi-scaled retinex. J Imaging Sci Technol 53(5):501–512
8. Jang IS, Lee TH, Ha HG, Ha YH (2010) Adaptive color enhancement based on multi-scaled Retinex using local contrast of the input image. Optomechatronic Technologies (ISOT), 2010 International Symposium on (pp.1–6). IEEE
9. Jang CY, Hyun J, Cho S, Kim HS, Kim YH (2012) Adaptive selection of weights in multi-scale retinex using illumination and object edges. In Proceedings of the International Conference on Image Processing, Computer Vision, and Pattern Recognition (IPCV) (p. 1). The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp)

10. Jang CY, Lim JH, Kim YH (2012) A fast multi-scale retinex algorithm using dominant ssr in weights selection. ISOCC 37–40. doi:10.1109/ISOCC.2012.6406919
11. Jobson DJ (1997) A multiscale retinex for bridging the gap between color images and human observation of scenes. IEEE Trans Image Process 6
12. Jobson DJ, Rahman Z, Woodell GA (1997) Properties and performance of a center/surround retinex. IEEE Trans Image Process 6(3):451–462
13. Kuang H, Chen L, Gu F, Chen J (2016) Combining region of interest extraction and image enhancement for night-time vehicle detection. Intelligent Systems IEEE:1–1
14. Land EH (1986a) Recent advances in retinex theory. Vis Res 26(1):7–21
15. Land EH (1986b) An alternative technique for the computation of the designator in the retinex theory of color vision. Proc Natl Acad Sci 83(10):3078–3080
16. Lin SCF, Wong CY, Rahman MA, Jiang G, Liu S, Kwok N et al (2015) Image enhancement using the averaging histogram equalization (avheq) approach for contrast improvement and brightness preservation. Comput Electr Eng 46:356–370
17. Qian X, Wang Y, Wang B (2012) Fast color contrast enhancement method for color night vision. Infrared Phys Technol 55(1):122–129
18. Rahman ZU, Jobson DJ, Woodell GA (2011) Investigating the relationship between image enhancement and image compression in the context of the multi-scale retinex. J Vis Commun Image Represent 22(3): 237–250
19. Robinson PE, Lau WJ (2012) Adaptive multi-scale retinex algorithm for contrast enhancement of real world scenes
20. Tarel JP, Hautiere N (2009) Fast visibility restoration from a single color or gray level image, in Proc. IEEE Int. Conf. Computer Vision (ICCV), Kyoto, 29 September–2 October 2009, pp. 2201–2208
21. Tsagaris V, Anastassopoulos V (2005) Fusion of visible and infrared imagery for night color vision. Displays 26(4–5):191–196
22. Wang W, Li B, Zheng J, Xian S (2008) A fast multi-scale retinex algorithm for color image enhancement. International Conference on Wavelet Analysis and Pattern Recognition 1:80–85
23. Xiao J, Song SP, Ding LJ (2008) Research on the fast algorithm of spatial homomorphic filtering. Journal of Image & Graphics 13(12):2302–2306
24. Xu Q, Jiang H, Scopigno R, Sbert M (2014) A novel approach for enhancing very dark image sequences. Signal Process 103(10):309–330
25. Yin S, Cao L, Ling Y, Jin G (2010) One color contrast enhanced infrared and visible image fusion method. Infrared Phys Technol 53(2):146–150
26. Zhao H, Xiao C, Zhao H (2015) Chapter 16: night color image enhancement via statistical law and retinex. Emerging Trends in Image Processing Computer Vision & Pattern Recognition:249–261
27. Zhou Z, Sang N, Hu X (2014) Global brightness and local contrast adaptive enhancement for low illumination color image. Optik - International Journal for Light and Electron Optics 125(6):1795–1799

Zhenghao Shi received the BS degree in material science and engineering from Dalian Jiaotong University, Dalian, China, in 1995, the MS degree in computer application technology from Xi'an University of Technology, Xi'an, China, in 2000, and the Ph.D degree in computer architecture from Xi'an institute of microelectronics, Xi'an, China, in 2005. In 2000, he joined Xi'an University of Technology, Xi'an, China. From 2000 to 2005, he was an assistant professor in the department of computer science and engineering at Xi'an University of

Technology. From 2006 to now, he is an associate professor of the department of computer science and engineering at the same University. During the period of 2006 to 2007, of 2008 to 2009, he was on leave with the department of computer science and engineering at Nagoya institute of technology, Nagoya, Japan, for image research as a postdoctral researcher, respectively. From 2007 to 2008, he was a research associate in the Kurt Rossmann Laboratories for Radiologic Image Research, the Department of Radiology, the Division of Biological Sciences, the University of Chicago. His research interests include neural networks for image processing and pattern recognition, computer-aided diagnosis, and image processing suggested by the human visual systems. He is a member of the IEEE, also a member of ACM.

Meimei Zhu is currently study for her bachelor degree in computer science and technology in Xi'an University of Technology, Xi'an, China. Her research interests focus on image processing.

Dr. Bin Guo is currently a professor with Northwestern Polytechnical University, China. He was previous a post-doctoral researcher of Prof. Daqing Zhang's research group at Institute TELECOM SudParis, France. He received his Ph.D. degree in computer science from Keio University, Tokyo, Japan, in 2009. He finished his Ph.D studies in the Anzai-Imai Lab, under the supervision of Prof. Michita Imaiand Prof. Yuichiro Anzai (president of JSPS in Japan). He received his B.E and M.E of Computer Sciencefrom Xi'an Jiaotong University (in China), in 2003 and 2006, respectively. His current research interests include: Ubiquitous Computing, Social and Community Intelligence, Mobile Crowd Sensing, and Human-Computer Interaction. He has served as an associate editor of IEEE Communications Magazine (ComMag), IEEE Trans. on Human-Machine-Systems (THMS), IEEE IT Professional (ITPro), ACM/Springer Journal of Personal and Ubiquitous Computing (PUC), Springer Frontiers of Computer Science (FCS), the guest editor of ACM Trans. on Intelligent Systems and Technology (TIST), IEEE Internet of Things (IoT), Elsevier Journal of Network and Computer Applications (JNCA), and so on. He has served as the general co-chair of the 12th IEEE International Conference on Ubiquitous Intelligence and Computing (IEEE UIC'15) and the program chair of IEEE CPSCom'16, IEEE UIC'13, the general chair of the IEEE 2014 International Workshop on Social and Community Intelligence (IEEE SCI'14@PerCom'14), the program vice-chair of the The 5th International Conference on Ambient Systems, Networks and Technologies (ANT'14) and the 14th IEEE International Conference on Computer and Information Technology (IEEE CIT'14), the vice-chair of the 9th National Pervasive Computing Conference (PCC'13), and so on. He serves as the TPC member for a number of conferences, including IEEE PerCom, MobiQuitous, MoMM, GPC, ICOST, EUC, etc. He is a senior member of IEEE and CCF, a member of ACM, a Technical Communittee member of Big Data at IEEE Communications Society, CSCWD at IEEE SMC Society, and CCF Prevasive Computing Group. He has published over 90 papers in refereed journals, conference proceedings and book chapters. His research was mainly funded by the National Natural Science Foundation of China (2012-2014, 2014-2017, 2014-2018), the National Basic Research Program of China (973; 2015-2019), Natural Science Foundation of Shaanxi Province (2013-2014), Basic Research Foundation of NPU (2011-2013), and partly funded by theEU FP7 Project (SOCIETIES, 2010-2011). He received the support of the Program for "New Century Excellent Talents in University(NCET)" of the State Ministry of Education in 2012 and the"Scientific and Technology New Star of Shaanxi Province" in 2013. He has won the the Second Class of Natural Scientific Award of the State Education Ministry of China in 2014, the Best Paper Award of IEEE CPSCom'13,BigDataSci'14, GPC'12, AMT'12, HHME'13, the IEEE Outstanding Leadership Award (@IEEE iThings'13), the CNCC'2013 Best Poster Award, and the Chinese Government Award For Outstanding Self-Financed Students Abroad in 2009.

Minghua Zhao received her Ph.D degree in computer science from Sichuan University, Chengdu, China, in 2006. After that, she joined Xi’an University of Technology, Xi’an, China. Currently, she is an associate professor of the department of computer science and engineering at the same University. Her research interests include image processing and pattern recognition.