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Enhancement and Noise Reduction of Very Low Light Level Images

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Abstract

A general method for image contrast enhancement and noise reduction is proposed in this paper. The method is developed especially for enhancing images acquired under very low light conditions where the features of images are nearly invisible and the noise is serious. By applying an improved and effective image de-haze algorithm to the inverted input image, the intensity can be amplified so that the dark areas become bright and the contrast get enhanced. Then, the joint-bilateral filter with the original green component as the edge image is introduced to suppress the noise. Experimental results validate the performance of the proposed approach.

1. Introduction

Images obtained at night usually seem dark due to low light especially when there is no or only weak light source nearby. Different from images of daytime, low-light level images concentrate their intensities mainly on the range of 1 to 20 and they contain lots of noise. As intelligent traffic and outdoor surveillance developing, image acquiring systems are demanded to work under various conditions, low light level included, which makes the image enhancement and noise reduction highly desired. Conventional image processing techniques, such as the well-known histogram equalization [1], mainly aim at contrast enhancement. It tends to enhance the darks at the cost of saturating bright, leading to structure information loss. The Retinex based methods (e.g. Multi-Scale Retinex [2]) often produce gray-out result when processing the very low light level data which is targeted in this paper. Recently, there has been a new idea for intensity transformation based on the observation that the inverted input low light image is similar to the image with a great deal of hazy [3]. Dong etc in [3] apply a dark channel prior based image de-hazing algorithm [4] to the inverted video frames and show its effectiveness. However, a drawback of the method is that there are boxes around where either bright spot exists or the scene depth is not continuous in resulting image, which is very visually disappointing. Another group of algorithms connected to our work are in the field of noise reduction. On one hand, the intrinsic noise level in low light image is higher than common. On the other hand, the noise is also amplified after the intensity transformation. Different from [3], a new method to remove the numerous haze or fog (visually similar) is proposed inspired by [5] by taking the features of low light level into account sufficiently. Then, an approach to noise reduction is presented to improve the resulting image. As is shown in figures, some visually pleasing results can be achieved.

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2. Enhancement of low light level image

As mentioned in [3], after inverting the input low light image as follows, the result looks like one acquired in haze.

$$I^c(x) = 255 - L^c(x) \tag{1}$$

Where c indicates the arbitrary one of the three color channels (RGB), L^c is the input low light level image, shown in Figure 1(a), I^c is the intensity of inverted image. Firstly, we focus our work on removing the haze. In computer vision and image processing field, the model as follows is widely used:

$$I(x) = J(x)t(x) + A(1 - t(x)) \tag{2}$$

Where I indicates the observed intensity and is also the hazy image, J is the scene radiance which is the just one we want to restore, A is the global atmospheric light and is the medium transmission expressed as

$t(x) = e^{-\beta d(x)}$ when the medium is uniform. To restore J from I , it is necessary to estimate the corresponding intensities of t and A . It is noted that in real hazy images the transmission is attenuated exponentially with the scene depth. The farther the scene is, the smaller the magnitude of the transmission and the denser the haze, vice versa. However, the image I we pay attention to is not a real haze one. Instead of attenuating with the scene depth, its transmission is closely connected to luminance. As shown in Figure 1(b), the darker the scene is, the denser the corresponding haze, so the transmission can be estimated based on luminance component. Due to a significant difference in the noise levels in the different input channels of low light level image [6], the luminance can be extracted as follows:

$$Y = 0.299 \times R + 0.587 \times G + 0.114 \times B \quad (3)$$

Note that the difference between the luminance image and the transmission map obtained by dark channel prior [4], it is necessary to make both of the images to be similar. The solution to this problem is using a parameter C minus the luminance map. The result after subtraction operation can be seen as a rough transmission map. As mentioned in [5], if the transmission is flatter, the corresponding result will contain more details, which means that the haze-free image will contain more details. Therefore, a medium filter to the rough transmission map is utilized just as [5]. In this way, the new transmission, as shown in Figure 1(c), can approximate the level of the haze resulting from low light. As for the estimation of atmospheric light A, the method based on dark channel image [3, 4, 5]is automatic and very robust, so it is also employed here. After the processing above, the haze-free image J can be recovered easily, and then the enhanced scene radiance can be obtained by inverting J , as shown respectively in Figure 1(d) and Figure 1(e).

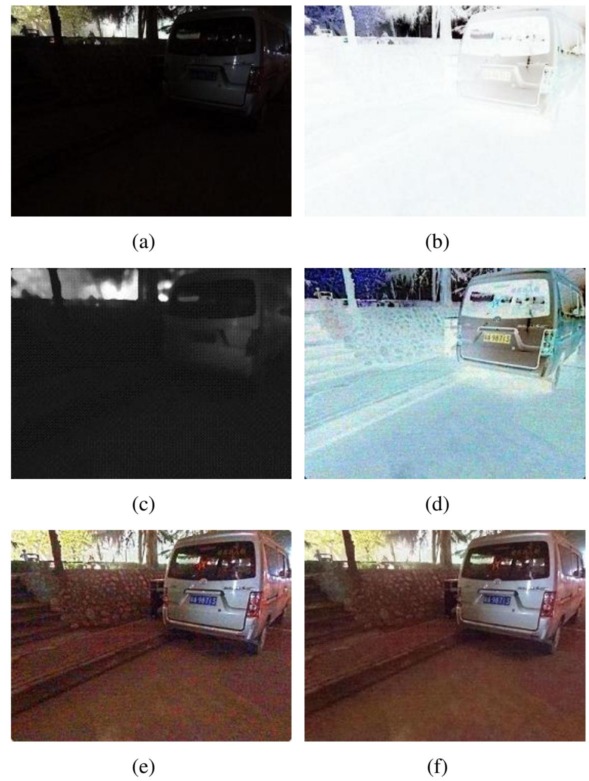


Figure 1. Enhancement and Noise Reduction of Very Low Light Level Images: (a) Input low light level image. (b) Inverted version from input image. (c) Estimated transmission map. (d) Haze-free image. (e) Enhanced bright image with noise. (f) Final output after joint-bilateral filtering.

3. Noise Reduction

The enhancement of the input data presented above can amplify its intensity significantly and make the hidden information in the low light appear, but the noise become more pronounced too, as shown in Figure 1(e). The next step is to suppress noise while maintaining edge and true details, producing a visually pleasing result. From Figure 1(e), it can be seen that it contains so-called false color noise which comes from the input low light level image. So far, there have been a good many methods to suppress noise and improve quality of the image. But very few published studies exists that especially target noise reduction in low light level images. One good example is the technique presented by Malm and Oskarsson [6]. Their approach is based on structure tensor and can deal with noise in very low light level video well, but it needs the information among successive frames and can not be used to handle the noise in a single image. In [7], the usefulness of applying the joint-bilateral filter for denoise and detail transfer is demonstrated. However, the technique presented there requires a pair of images of low-light environments: one with flash to capture details and one without flash to capture ambient illumination, the latter containing lots of noise. Inspired by this approach, to apply joint-bilateral filter to solving the problem in this subsection, a second image with no or little noise but abundant detail is needed in addition to the image result from the process described in section 2. Fortunately, it is noticed that in very dark images the blue channel often has a relatively higher noise level [6], and it is found that the green channel often has a relatively lower noise level of the three ones in our observation of a variety of very low light images. Moreover, since the green channel accounts for more proportion than the blue or red one in Bayer pattern according to which the pixels are usually arranged in CMOS or CCD sensor and human visual system are very sensitive to green, there is little chance that the green channel information of the input low light level image is close to zero. That is to say, the green component of the original input can be used to supply edge or detail, severing as a second image in joint-bilateral filter. Next, bilateral filter will be described and it will be shown how to apply joint bilateral filter using the edges of green component to reduce the noise.The bilateral filter is defined as a non-iterate means of smoothing images combining a classic low-pass filter with an edge-stopping function that attenuates the filter kernel weights when the intensity difference between pixels is large. From [8], bilateral filter computers the value of pixel x for the enhanced image E as:

$$E_x^B = \frac{1}{\omega_x} \sum_{y \in \Omega} g_s(\| x - y \|) g_r(| E_x - E_y |) E_x \quad (4)$$

Where ω_x is a normalization term, a sum weight of the local patch centered by pixel x:

$$\omega_x = \sum_{y \in \Omega} g_s(\| x - y \|) g_r(| E_x - E_y |) \quad (5)$$

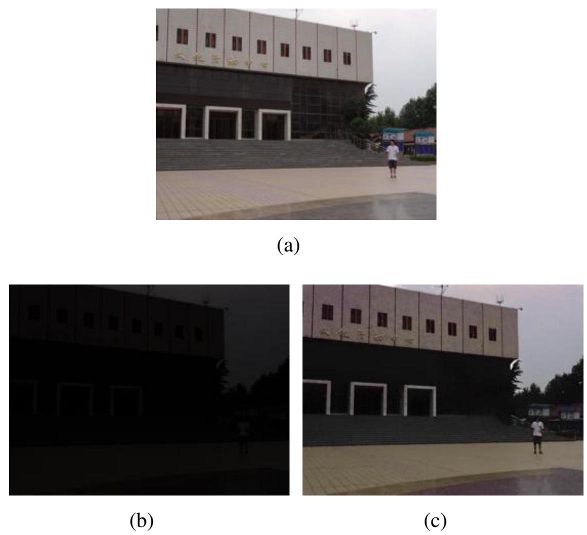
The function g_s sets the weight in spatial domain based on the distance between the pixels, while g_r sets the weight on the range based on intensity differences, called edge-stopping function. Generally, both functions are Gaussians with widths determined by the standard deviation σ_s and σ_r respectively. Since the bright image E is noisy, the local smoothing of basic bilateral filter will be effected by the central pixel which is disturbed by noise. As mentioned before, the green component contains much less noise and can be considered better estimate of the true details than the restored image E. Therefore, the joint bilateral filter is introduced, computing the edge-stopping function with the green component image G instead of E.

$$E_x^{Jb} = \frac{1}{\omega_x} \sum_{y \in \Omega} g_s(\| x - y \|) g_r(| G_x - G_y |) E_x \quad (6)$$

Where ω_x is modified similarly. The brute force implementation of the bilateral filter is computationally expensive, so Paris and Durand's single processing method [9] is chosen for the acceleration. The parameters σ_s and σ_r are set as 16 and 1 respectively for all results shown in this paper. The filtered version of Figure 1(e) is shown in Figure 1(f).

(a) (b) (c) (d)

Figure 2. (a) and (c) Set of test image pairs. (b) and (d) The results of the proposed algorithm.



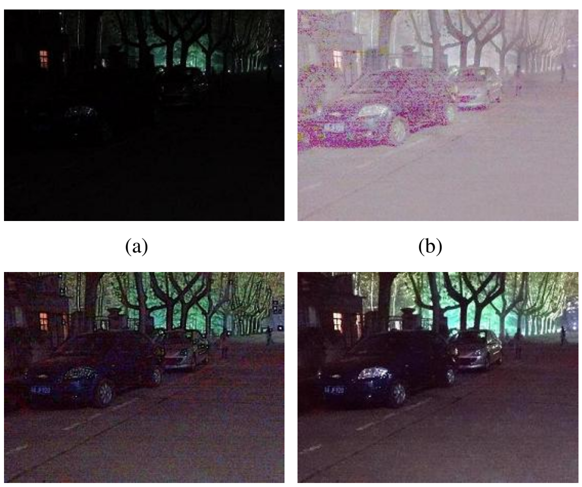
(a) (b) (c)

Figure 3. (a) Reference image in day time. (b) Input low light level image. (c) Enhanced image using the proposed algorithm.

4. Experimental Results

The proposed method was tested on several images with various degrees of darkness and noise levels. Examples of the enhancement results of the proposed algorithm are shown in Figure 2. The original low light level images in Figure 2(a) and Figure 2(c) exhibit very little scene information due to the low illumination level. The enhanced results are shown in Figure 2(b) and Figure

2(d) and the ellipses point out the areas with notable enhancement. More experimental results with a reference image at the same place in day time are shown in Figure 3. The method is also compared with the Multi-Scale Retinex [2] and the method based on dark channel prior [3]. In the experiments, the patch size is set to 15×15 for an 720×540 input. Other parameters are set empirically as follows: $C = 1.06$, $\sigma_s = 16$, $\sigma_r = 1$, $\sigma 1_{msr} = 12$, $\sigma 2_{msr} = 50$, $\sigma 3_{msr} = 120$. In our experiments, we perform the local min operator using Marcel van Herk's fast algorithm [10] whose complexity is linear to image size. It takes about 5 seconds to process a 720×540 pixel image on a PC with a 2.6 GHz Intel Pentium(R) Dual-Core CPU. The visual comparison is presented in Figure 4. From Figure 4, it can be seen that the contrast is very low and the whole image seems gray-out in result by method in [2]. Although the method in [3] can make the low light image bright, it generates black boxes around the bright spots and is degraded by serious noise. In contrast, our method produces satisfying results with bright scene and little noise.



(a) (b) (c) (d)

Figure 4. From top-left to bottom-right: input very low light level image, results by Multi-Scale Retinex in [2], method based on dark channel prior in [3] and the proposed method respectively.

5. Conclusions and Future Work

A very simple but effective method for enhancement and noise reduction for very low light level images is proposed in this paper. By applying an improved haze removal algorithm to inverted input data, the low light level image can be enhanced. The joint-bilateral filter with the original green component as the edge image can achieve noise reduction while simultaneously preserving the edge. Experimental results show that the proposed method outperforms some current state-of-the-art methods in visual quality.

Future work includes researching other noise removal filters and make comparison between them. Current challenges include speeding up the processing to apply it to real-time video and improving robustness to changing lighting conditions, so we also intend to investigate noise modeling in low light images and enhance them based on these models in the future.

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