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Improvement of low illumination image enhancement algorithm based on physical mode

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ABSTRACT

The low illumination images always have low brightness, low dynamic range and high noise, because of these characteristics, an improved enhancement algorithm is proposed for low illumination image. Considering that low illumination image enhancement will amplify the noise, it needs to reduce the noise before image enhancement. Firstly, using BM3D (block matching 3D) for image denoising in YCbCr space, then improving the transmission for image enhancement based on the physical model in HSI space. Experiments show that the method can effectively improve the brightness and contrast, enhance the detail of the image, reduce noise, and get a good visual effect.

KEYWORDS

Low illumination; Image enhancement; Physical model; Block matching 3D.

INTRODUCTION

Low light conditions have no assistant light source, images obtained on rain day, at night or in the mine usually have poor quality and blurred details, these images are not applied to machine recognition and target tracking, so the resulted is unusable for practical applications. As image acquiring systems are demanded to work under low light conditions, the image enhancement and noise reduction is highly desired.

Conventional image processing techniques such as histogram equalization which is the most widely used, it enhances contrast through simple computing, but leads to structure information loss[1]. The Retinex can maintain color constancy of human vision. However, it causes some problems, such as halo effect, gray-out result and noise amplification[2][3]. In addition, Zhao etc in[4] proposed a spatial domain enhancement method combined gradient transform with high boost filter, Yin etc in[5] adopted bilateral filter and luminance statistics in order to compensate brightness, A nonlinear contrast enhancement based on human visual system was presented in[6], Space-variant luminance map has been used in[7] to enhance the low illumination image, A homomorphic filtering based on HSV space in[8] solves the problem of color cast, these methods do not consider the characteristics of low illumination image, the results are not ideal. In recent time, Dong etc in[9] propose contrast enhancing method based on dark channel prior, and then Zhang etc in[10] apply image de-hazing algorithm used luminance component to the inverted low illumination image, the algorithm is fast and effective, however, when the bright spot exists or the scene depth is discontinuous, the boxes will appear which is disappointing.

To solve the above problems, the paper proposes an improved algorithm building upon work in[10]. Aiming at the serious noise of low illumination image, we put the image de-noising before enhancement, which could avoid increasing the noise when enhance the image. Besides, improving the estimate of the transmission overcomes the "details lost" phenomena because of the rough luminance transmission.

LOW LIGHT IMAGE DENOISING BASED ON BM3D

Low illumination images have very high noise, and there is a high correlation between the image and the noise, directly enhancing the image will increase noise accordingly, so we need to reduce the noise before. Analysis of low illumination image[11], the noise mainly includes impulse noise generated during transmission and storage, Gaussian noise produced by various components and transmission channel, and poisson noise under the condition of very low illumination, where poisson noise impacts on the low illumination image biggest, therefore, 3D de-noising is more suitable, Dabov K, Foi A etc[12] proposed a three-dimensional block matching de-noising (BM3D) is considered as the best de-noising method at present, this method is a kind of enhanced sparse representation based on transform domain. The algorithm steps is illustrated in Figure (1)., and the main ideas and steps are as follows,

Firstly, stacking similar 2D image neighborhoods into a 3D array that called grouping, then getting the optimal estimation using collaborative filtering, the obtained block estimates may overlap after the above processing, and thus we need to aggregate these multiple estimates by weighted averaging. In order to obtain a better result, above general procedure is used repeatedly.

Image de-noising in HSV color space need to deal with each channel, however, color is sensitive to the change of H and S component, especially H component, therefore, de-noising in HSV color space will lead to color distortion. In YCbCr space, because the human eyes are relatively sensitive to Y component but not sensitive to Cb and Cr component, so the de-noising does not cause color inconsistency. Considering de-noising algorithm operation efficiency and color fidelity simultaneously, we use the YCbCr space as the de-noising experimental scene, in YCbCr space, analysis of noise level of each channel, the luminance component Y contains higher level noise, therefore, this article only deals with the noise on the Y component, that improves the processing efficiency.

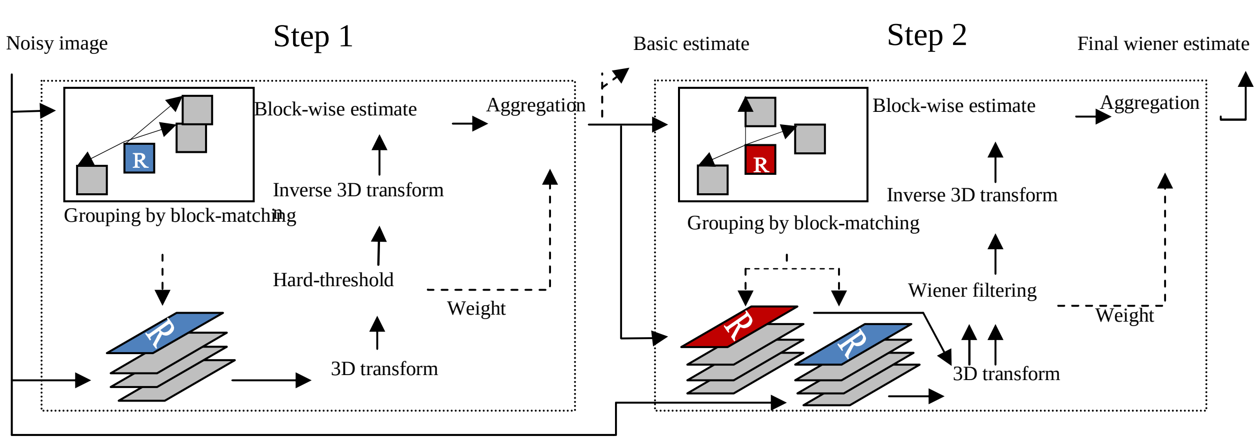

Figure 1 : Flowchart of BM3D de-noising algorithm

RELATED WORK

This algorithm is based on the physical model, parameter estimation is the key in the physical model, Koschmieder physical model and dark channel prior is used to estimate parameter.

Physical model

The classical physical model can be expressed as follows:

$$I(x) = J(x)t(x) + A(1 - t(x) \quad \textbf{(1)}$$

$$t(x) = e^{-\beta d(x)} \quad \textbf{(2)}$$

Where A is the atmospheric light, x is the spatial location, $I(x)$ is the intensity of the observed image that is the fog image, $J(x)$ is the clear image after dehazing, $t(x)$ is the transmission function, β is the atmospheric scattering coefficient, and $d(x)$ is the scene depth. In (1), the first term is the direct attenuation caused by the atmospheric scattering during transmission from the scene to imaging devices, and the second term is the airlight caused by natural light scattering.

Dark channel prior

He etc[13] get the dark channel prior by observation and statistics of 5000 images, and this theory creates a new field on image dehazing. To any image J, we define the dark channel as follows:

$$J^{\text{dark}}(x) = \min_{y \in \Omega(x)}(\min_{c \in \{r,g,b\}} J^c(y)) \quad \textbf{(3)}$$

Where J^c is a color channel of J, $\Omega(x)$ is a square area centered at x. According to dark channel prior, if J is an outdoor haze-free image, J^{dark} is always very low and tends to be zero.

THE PROPOSED ENHANCEMENT OF ILLUMINATION IMAGE

In order to enhance the image that is processed with de-noising algorithm, the enhancement in this article is proposed on the base of physical model. According to the observation, the pixel of every color channel in sky and far background part will be high after low illumination image reversed. Meanwhile, there has at least one channel luminance is low in the non-sky area which is similar with the image that get under the condition of thick fog. Therefore, it could be work that apply de-hazing algorithm to low illumination image that has been reversed for enhancing it. It means that the enhanced low illumination image could be got after reversing the reversed low illumination image that is processed by de-hazing algorithm. During the processing of de-hazing in this paper, Luminance transmission map instead of atmospheric transmission map in physical model is estimated by component I in HIS color space, which will improve the luminance of the enhanced image and subtilize the details after gaining the thinning from Retinex.

Enhancement of low illumination image based on physical model

Considering the enhancement of low illumination image, it is the first step to reverse the initial image R, and the formula is stated as follows:

$$I^c(x) = 255 - R^c(x) \quad \textbf{(4)}$$

c stands for RGB color channel, $I^c(x)$ is the reverse of low illumination image, $R^c(x)$ is initial low illumination image. After that, we can dehaze I^c with formula (1) and make use of dark channel prior to estimate atmospheric light A with He[8] method. First and foremost, we choose 0.1% pixel that is the maximum luminance in dark channel, then the pixel corresponding to the maximum pixel in initial image is atmospheric optical. The formula for Restoring image is shown in (5):

$$J(x) = \frac{I(x) - A}{t(x)} + A \quad \textbf{(5)}$$

The image that has been defogged will be applied to formula (4), then it could get enhanced low illumination image E, as illustrated in Figure (2).(e).

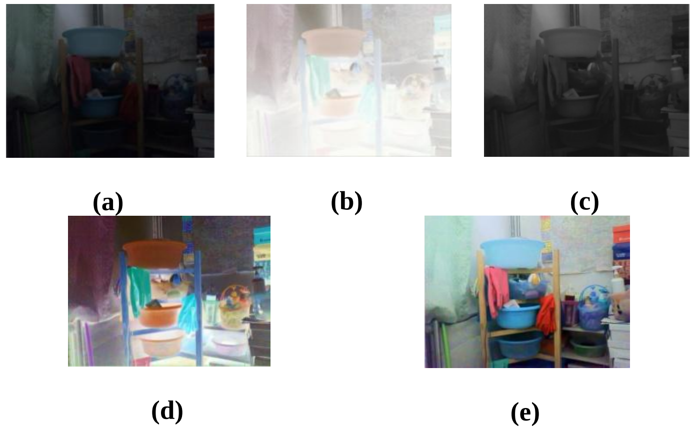

Figure 2 : (a) Input low light image, (b) Inverted result from input image, (c) Estimated transmission map, (d) Haze-free image, (e) Final output

It could be seen from formula (5) that the point of restoring image is estimated luminance transmission map t(x) reasonably, so do this paper. The estimation of luminance transmission map will be introduced concretely in next chapter.

Luminance transmission map estimation of low illumination image

Apply dark channel prior to fog physical model, in the case of the fact that A is known, assume that transmission rate is constant in local area, minimize two sides of formula (1), as shown in (6):

$$\min(\min_{y\in\Omega(x)}(\frac{I^c(y)}{A^c})) = t(x)\min_c(\min_{y\in\Omega(x)}(\frac{J^c(y)}{A^c})) + (1-t(x)) \quad (6)$$

Under the condition of haze-free, dark channel value is close to zero, we can get t(x) as follows:

$$t(x) = 1 - \min_{c\in\{rgb\}}(\min_{y\in\Omega(x)}(\frac{I^c(y)}{A^c})) \quad (7)$$

It could be seen from (2) that t(x) is decreased with the increase of scene depth, the farer scenery has the smaller transmission rate, as the same as the thick fog area. However, we find that the reversed image of low illumination image is not real fog image, its transmission map and brightness is related to each other closely which is not like the fog image that decreased with scene depth. In this case, the transmission map could be estimated based on brightness component, because the darker place in initial image will make the fog thicker in the reversed image accordingly, as illustrated in Figure (2).(b).

If we would like to use luminance transmission map instead of initial atmospheric transmission map to restore image, transit RGB image to the image that make the chromaticity and luminance apart. The common color space is HSI, HSV, YCbCr, Lab etc. Each color space has advantage and disadvantage. Zhang estimate transmission map with the component of component Y in YCbCr space, but if we enhance the lumination in YCbCr will lead to the color fade away. HSI start from the visual system of human, which keep the constancy of color, so it wouldn’t change the color if we expand the luminance and contrast in HSI. The luminance could be stated as follows:

$$I = (R+G+B)/3 \quad (8)$$

Brightness component image is quite different with the atmospheric transmission map. In order to make the luminance transmission map instead of atmospheric transmission map, and make both approximate on effect and function, we can use the suited parameter C minus the pixel values of each point, the minus result make the inverse transformation, but the estimated transmission we get in this method is very rough, the effect of processing the image is not that satisfied. So we have to refine the luminance transmission. MSR has multiple scales, which is a combination of maximum, medium and minimum scale advantage can realize compression and increase the edge details in the dynamic range at the same time. This paper will use MSR process luminance component, as shown in formula (9):

$$I_m(x,y) = \sum_{n=1}^{N} W_n(\ln I(x,y) - \ln[F_n(x,y) * I(x,y)]) \quad (9)$$

After MSR processing, the luminance component will get reverse color transformation, then get the coarse estimates of the transmission:

$$\tilde{t}(x) = C - I_m \tag{10}$$

Median filtering the outline of luminance transmission in the estimated transmission, for making defogged image contain more detail information[14], thus got the final luminance transmission map, as shown in Figure (2). (c).

RESULTS

According to the above algorithm, low illumination image enhancement, Figure (3). shows the enhanced results and the estimated luminance transmission map in two different scenes. From Figure (3)., we can see that the proposed algorithm eliminates the noise effectively and improves brightness and edge details excellently. Meanwhile, luminance transmission map details also have certain advantages.

(a) (b) (c)

(d) (e) (f)

Figure 3 : (a) and (d) Input low light image, (b) and (e) Estimated transmission map, (c) and (f) Final output

Figure 4 : Left: low light examples. Middle: results by Zhang's algorithm. Right: results by the proposed algorithm

To further verify the effectiveness and the superiority of the proposed algorithm, Figure (4). shows the comparison of Zhang algorithm and the proposed algorithm in four different scenes. From Figure (4), color distortion is serious by Zhang algorithm, and the result by the proposed algorithm is better in color fidelity. In terms of de-noising, the proposed algorithm is obviously better than that of Zhang. In addition, the processed image brightness is also slightly higher than that of Zhang.

In addition to the subjective visual effect, it also need the objective parameters to evaluate the superiority and inferiority of the proposed algorithm. To the enhanced image, it will evaluate from two aspects -image fidelity and de-noising. Therefore, we introduced the AMBE (absolute mean brightness error) and PSNR (peak signal to noise ratio) as objective evaluation parameters of enhancement effect. AMBE measures the image fidelity, the smaller AMBE value is, the higher fidelity will be. PSNR measures de-noising effect, the greater the PSNR is, the better de-noising effect will be. TABLE 1 lists the contrast result of objective parameters of four images in Figure (4)..

TABLE 1 : The contrast result of quality evaluation parameters of four example images

Input image example	Quality evaluation	Zhang's algorithm	The proposed algorithm
Example 1 of Figure (4)	AMBE	0.1032	0.0866
	PSNR	61.3822	62.0329
Example 2 of Figure (4)	AMBE	0.1775	0.1550
	PSNR	66.8528	67.9959
Example 3 of Figure (4)	AMBE	0.1271	0.1159
	PSNR	63.4073	63.2627
Example 4 of Figure (4)	AMBE	0.1509	0.1349
	PSNR	60.9805	61.3331

Seen from the results, in contrast of the image from three groups, AMBE we get from the algorithm in this paper are less than the algorithm of Zhang, PSNR are more than Zhang algorithm, so it clearly shows that this algorithm also has certain advantage of fidelity and de-noising.

CONCLUSIONS

According to the characteristics of low illumination image, we propose a low illumination enhancement algorithm based on physical model. Putting image de-noising before the enhancement of low illumination image can avoid the problems that noise amplification caused by the image enhancement. The images obtained at night contain high noise, and most of the noise is the poisson noise, so 3D de-noising algorithm suits the image de-noising. Using BM3D algorithm to deal with Y component only could ensure de-noising and avoid the color distortion at the same time, and improve the efficiency. When we do de-hazing for the inversed low illumination image, Retinex theory and brightness figure are combined to estimate luminance transmission map, which will further improve brightness and contrast of the image, strengthen the details as well.

CONFLICT OF INTEREST

This article content has no conflict of interest

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