A fusion-based enhancing approach for single sandstorm image

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Abstract—In this paper, a novel image enhancing approach focuses on single sandstorm image is proposed. The degraded image has some problems, such as color distortion, low-visibility, fuzz and non-uniform luminance, due to the light is absorbed and scattered by particles in sandstorm. The proposed approach based on fusion principles aims to overcome the aforementioned limitations. First, the degraded image is color corrected by adopting a statistical strategy. Then two inputs, which represent different brightness, are derived only from the color corrected image by applying Gamma correction. Three weighted maps (sharpness, chromaticity and prominence), which contain important features to increase the quality of the degraded image, are computed from the derived inputs. Finally, the enhanced image is obtained by fusing the inputs with the weight maps. The proposed method is the first to adopt a fusion-based method for enhancing single sandstorm image. Experimental results show that enhanced results can be improved by color correction, well enhanced details and local contrast while promoted global brightness, increasing the visibility, naturalness preservation. Moreover, the proposed algorithm is mostly calculated by per-pixel operation, which is appropriate for real-time applications.

I. INTRODUCTION

The sandstorm, which brings amount of disasters, has happened in the whole world more frequently in recent years. One of the disadvantages is degrading the visibility significantly, which directly impacts on traffic safety, surveillance system, intelligent vehicle and remote sensing systems. Since the light is absorbed and scattered by floating sand and dust in sandstorm, the observed image is degraded by color distortion, low-visibility, fuzz and darkness.

Enhancement and restoration the visibility of degraded images in bad weather conditions have received much attention. For image enhancement technique, some effective and efficient algorithms have been proposed [1][2][3][4][5][6][7] to deal with color distortion, low-contrast, darkness and naturalness preservation. When tackling sandstorm images, the mentioned algorithms fail to process since the color and detail information are lost seriously due to the absorption and scatter of the light. Recently, a kind of fusion-based algorithm is proposed and has a good performance on dealing with underwater images

[8] and haze images [9]. For image restoration technique, most algorithms are generally based on the dichromatic model [10] and mainly focus on hazy or foggy images. Different priors are found and used to invert the degrading processing. Tan [11] restored the visibility by manipulating contrast in observed degraded images. Fattal [12] adopted independent Component Analysis (ICA) to estimate scene radiance and transmission to improve the quality of haze images. Taral [13] used median filtering to estimate depth to recover scene. A novel prior, which called dark channel prior [14], is proposed to estimate transmission and has a satisfactory result on single image haze removal. A non-local total variation strategy [15]is used as a regularization to estimate transmission and latent image. Even though the aforementioned restoration methods have an effective result on hazy or foggy images, they also fail to process sandstorm images. Since the radius of particles in sandstorm is nearly 25μm [16], which is much larger than haze (0.01~1μm) and fog (1~10μm) [10], the dichromatic model and different priors are no longer applicable.

According to the analysis mentioned above, for enhancing sandstorm images, a special strategy is needed to solve this challenging task. In this paper, a simple, fast and effective approach is proposed to enhance single sandstorm image based on a fusion technique. Different with conventional image fusion strategies, which require several input images [17] , the proposed algorithm derives two input images and weight maps from only one observed image. The main steps of the proposed algorithm are as follows. Firstly, based on a statistical method, the sandstorm image is pre-processed to solve the color distortion and make a natural appearance. Then two input images, which contain different luminance information to make a tradeoff between brightness and darkness, are derived from the color corrected image by simply using Gamma correction. In order to effectively utilize the useful information of the two derived inputs, three weighted maps (sharpness, chromaticity and prominence) are computed to enhance specify features. Finally, the enhanced image is obtained by fusing the two inputs which are weighted by the normalized weight maps.

The proposed approach is the first to enhance single sandstorm image by adopt a fusion-based method. One advantage of the proposed algorithm is that, additive images and other complex information about the sandstorm are not required.

All the inputs and weight maps are derived from single observed sandstorm image. Another advantage is, inspired by dark channel prior [14] and bight channel prior [18] , a new prominence weighted map is proposed to salient objects that lose prominence. Moreover, the proposed algorithm is mostly calculated by per-pixel computation, which is easy to implement and appropriate for real-time applications. Experimental results demonstrate that enhanced images can be improved by color correction, well enhanced details and local contrast while promoted global brightness, increasing the visibility and naturalness preservation.

II. FUSION-BASED ENHANCING ALGORITHM

The proposed fusion-based enhancing algorithm for single sandstorm image is described in this section. The fundamental concept is to extract two input images and weight maps that derived from single observed image. Each input and weight map represents different important features. Then the derived inputs and weighted maps are combined by fusing operation to obtain the final enhanced image, which is synthesized multiply features. There are mainly three steps of the proposed algorithm: deriving two inputs, computing weight maps and fusing the inputs and weight maps. Fig. 1 is the flow chart of the proposed algorithm.
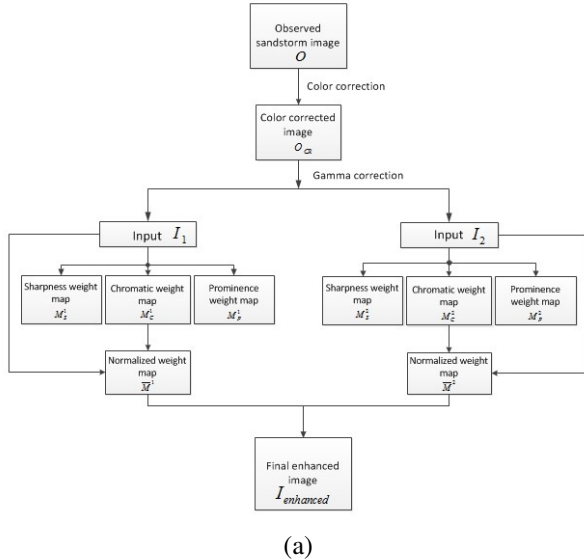

(a)

Fig. 1.   The flow chart of the proposed approach

A. Inputs

Since amount of particles are floating in air under sandstorm condition, light is absorbed and scattered seriously. Generally, the sandstorm image appears yellow since the yellow light has the largest penetrability and scattering. Traditional white balancing algorithms [19][20] are not useful due to the absorbed colors are difficult to be restored. Before deriving the inputs, a color corrected approach based on statistical method is adopted to remove the color cast and make a natural appearance.

The observed sandstorm image is defined as O and the color correcting process is as follows. First, the maximum and minimum of color shifting in color channel (RGB-channel) is calculated as:

$$O_{\max}^c = O_{\mathrm{mean}}^c + \mu O_{\mathrm{var}}^c$$
$$O_{\min}^c = O_{\mathrm{mean}}^c - \mu O_{\mathrm{var}}^c \tag{1}$$

where $c \in \{R, G, B\}$, O_{mean}^c is the mean value of the channel, O_{var}^c is the mean square error, μ is a parameter to control the color corrected images saturation. $O_{\max}^c$ and $O_{\min}^c$ are the maximum and the minimum of color shifting respectively. Then, the color corrected image is calculated as:

$$O_{CR}^c = \frac{O^c - O_{\min}^c}{O_{\max}^c - O_{\min}^c} \times 255 \tag{2}$$

where O_{CR} denotes the color corrected image. This operation based on simple statistical method can remove the color cast effectively.

While the color correction cannot address the problem of non-uniform luminance due to the absorption and scattering of the light, therefore two inputs with different luminance are derived to make a tradeoff between brightness and darkness. The two inputs are obtained by adopting Gamma correction of O_{CR} to adjust luminance. The Gamma correction is defined as follows:

$$V' = 255(\frac{V}{255})^{\frac{1}{\gamma}} \tag{3}$$

where V is the V channel in HSV color space that represent luminance information, γ is the adjusting parameter. The first input I_1 is derived by setting γ as 1.3 while the second input I_2 is derived by setting γ as 0.7. the first input I_1 with high luminance can lightening darkness regions, and the second input I_2 with low luminance has the effect of suppressing excessive brightness. This Gamma correction operation is to produces an appropriate uniform luminance and makes a balance between brightness and darkness.

B. Weight Maps

After the color correction and luminance adjustment, the derived inputs still suffer from fuzz and low-visibility. In order to overcome these unpleasant appearances, three weight maps (sharpness, chromaticity and saliency) are introduced to further improve the quality of degraded images.

The first weight map is **sharpness weight map** (M_S) which is used to deal with fuzz. This map is obtained by adopting the contrast local adaptive histogram equalization (CLAHE) [21] on each input luminance component, i.e. the V channel. Details and edges can be enhanced effectively meanwhile noise amplification can be avoided. This weight map makes the outline of distant objects observed clearly, in other words, the depth can be stood out.

Generally, the human visual pleased with images with high saturation [9]. Therefore, the second weight map is **chromatic weight map** (M_C) to adjust the saturation gain. This map is obtained by adopting the algorithm mentioned in [9]:

$$M_C^k(x,y) = \exp(-\frac{(S^k(x,y)-1)^2}{2\sigma^2}) \qquad (4)$$

where S is the S channel in HSV color space, k indexes the derived inputs, σ is the standard deviation. Since the range of saturation value is [0, 1], equation (4) makes the saturated regions in original inputs can be enhanced in the final result.

In sandstorm environment, objects prominence is usually lost. Inspired by dark channel prior [14] and bight channel prior [18], the **prominence weight map** (M_P) is introduced to emphasize objects. After color correction operation, the two inputs appearance likes haze environment. Based on this observation, the dehazing algorithm using dark channel prior in [14] is adopted as the first process on the two inputs. In order to avoid the halo artifacts and reduce the computing complexity, the dark channel is calculated by per-pixel operation. The haze-free image has the effect of emphasizing objects to some degree while cannot highlight the saliency. According to the bight channel prior [18], we simplify that at least one pixel has very high intensity in one color channel in most objects and this is used to extract objects saliency. Then the prominence weight map is obtained by calculating the bright channel of the haze-free images. As the same with dark channel calculation, the bright channel is also computed by per-pixel:

$$M_P^k(x,y) = \max_{c \in \{R,G,B\}}(J_c^k(x,y)) \qquad (5)$$

where J is the haze-free image from the input by using dehazing algorithm.

C. Fusion Process

In order to generate consistent results, each weight M^k are obtained by summing the previous computed weight maps: M_S^k, M_C^k and M_P^k. Then the final weight map for each input is:

$$\overline{M}^k(x,y) = \frac{M^k(x,y)}{\sum_k M^k(x,y)} \qquad (6)$$

The enhanced image is calculated by fusing the derived inputs with the weight maps:

$$I_{enahcned} = \sum_k \overline{M}^k(x,y)I_k(x,y) \qquad (7)$$

where $I_{enahcned}$ denotes the final enhanced image. The normalized weight maps constrains the range of intensity in the result is the same as the inputs. In next section, experimental results are shown to demonstrate the effectiveness of the proposed methods.

III. Experimental results and analysis

In this paper, all experimental images are processed by Matlab R2012a on a PC with an Intel Core i3 CPU, 4GB RAM. The parameter μ in equation (1) is fixed as 3, and the default value of the standard deviation σ is = 0.3 in equation (4), as the same in [9].

Figure. 2 shows one of the experimental results. The enhanced result, derived inputs and corresponding normalized weight maps are displayed. As can be seen, the two derived inputs with different luminance make a balance with brightness and darkness. The input with low luminance can avoid over-enhancement, such as distant objects in the high luminance input, which can lighten darkness regions. Meanwhile the corresponding normalized weight maps synthesize different features of derived inputs to improve the degraded images quality. Comparing with the observed sandstorm image, the final enhanced result has the character of color correction, improved visibility and global brightness, well enhanced details and local contrast.
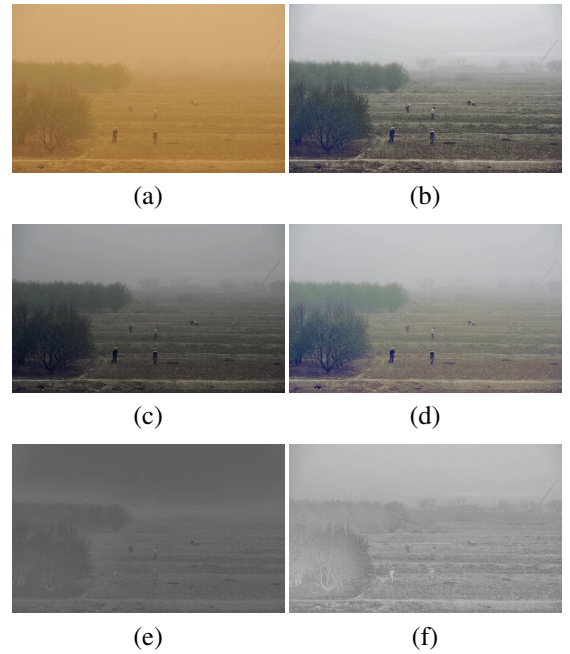

Fig. 2. Top: the sandstorm image and the enhanced result; Middle: the two derived inputs with different luminance; Bottom: the corresponding normalized weight maps $\overline{M}$.

In figure. 3 and figure. 4, comparisons with Multi-Scale Retinex with Color Restoration (MSRCR) [2], Generalized Unsharp Masking (GUM) [4] and Tarels algorithm [13] are shown. It is clearly that all the other three algorithms fail to recover color information, which makes their results look unnatural. The results by MSRCR algorithm [2] are over-enhancement meanwhile the distant objects become more fuzz. This due to the MSRCR algorithm merely takes reflectance as the final result without considering other features. The results by GUM algorithm [4] have a good performance

(a)

(b)   (c)   (d)   (e)

Fig. 3. Comparison with other algorithms: (a) the sandstorm image. (b) the result of MSRCR [2]. (c) the result of GUM [4]. (d) the result of Tarel [13]. (e) the result of proposed approach.

(a)

(b)   (c)   (d)   (e)

Fig. 4. Comparison with other algorithms: (a) the sandstorm image. (b) the result of MSRCR [2]. (c) the result of GUM [4]. (d) the result of Tarel [13]. (e) the result of proposed approach.

on improving contrast while still over-enhancement. Since the GUM algorithm cannot make a tradeoff between low-frequency and high-frequency. The results by Tarels algorithm [13] have an obvious boundary due to the dichromatic model is not applicable to the sandstorm condition, which makes the atmospheric veil cannot be estimated correctly. The enhanced results by proposed approach have an improvement on color correction, naturalness preservation, contrast and global brightness promotion, well enhanced details and increasing the visibility. Since the proposed approach is based on fusion method which synthesizes multi-features of the two derived inputs, the final enhanced images outperforms other three algorithms.

Moreover, the computation time is satisfactory since most

calculations are based on per-pixel operations. It takes about 1.03 seconds to process a color image with size 900×600. In comparisonthe MSRCR algorithm takes 1.02 seconds per image, the GUM algorithm requires 2 seconds and Tarels method needs 1.5 seconds. Based on hardware accelerating, the proposed approach can be appropriate for real-time applications.

IV. Conclusion

In this paper, a fusion-based approach is proposed to enhance single sandstorm image. The proposed approach is the first to solve this challenging problem by utilizing only one degraded image. First, two inputs with different luminance are derived from the color corrected sandstorm image. Then

three weight maps that contain different important information are computed to enhance corresponding features. The final enhanced image is obtained by fusing the two inputs with the weight maps. Experimental results demonstrate both the effectiveness and efficiency of the proposed approach.

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