Image enhancement focusing on hazy and non-uniform illumination images

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***Abstract*—This paper presents a unified method for fast single image enhancement without using any extra information. Adopting a linear combination model of direct attenuation and un-uniform illumination, we describe a unified approach to handle such degraded images with a strategy that gracefully bridges the gap between those two extremes. The proposed approach simultaneously dehazes images and enhances sharpness by means of individual treatment of the RGB component of the residual images. Simulation results on a variety of outdoor degraded images demonstrate that the proposed method achieves short computation time and good restoration for visibility and color fidelity.**

Keywords—Single image dehazing, dark channel prior, non-uniform illumination images, image quality assessment

I. INTRODUCTION

Recently, single image dehazing algorithms have been developed to overcome the limitation of multiple image dehazing approaches. These algorithms make use of strong assumptions or constraints to remove haze from a single image. Tan [1] maximized the contrast of a hazy image by assuming that a haze-free image has a higher contrast ratio than a hazy image. However, this method yields halo artifacts. Fattal [2] decomposed the scene radiance of an image into the albedo and the shading and proposed an approach that can remove haze locally but cannot restore densely hazy images. Kopf et al. [5] proposed a method based on the 3D model of the scene, yet it is application dependent and needs extra inputs from an expert. Tarel and Hautiere[3] proposed a fast visibility restoration algorithm based on linear operations but there are too many parameters to be adjusted. He et al. [4] proposed a method based on dark channel prior and the airlight map is estimated using dark channel prior and refined by soft matting. Ancuti et al. [6] significantly reduced the complexity of He's algorithm by modifying the block-based approach to a layer-based one. In addition, He et al.'s algorithm has been adopted and improved by many researchers [7,8,9,10]. Despite all the fruitful achievements made so far, there lacks an effective method to accurately estimate atmospheric light at present.

In this work, we propose a novel enhancement algorithm for images based on the optimized contrast enhancement. The rest of the paper is organized as follows. Section 2 presents the proposed algorithm in details, including the scheme and flow of the unified approach. Section 3 presents experimental results for outdoor images, which is followed by concluding remarks of our work in Section 4.

II. HAZY REMOVAL BASED ON DEGRADATION MODEL

A. Key idea of the proposed dehazing method

According to physical mode, the low reflectivity of the target is defined as $\rho(x,y)\to 0$, and $V(x,y)=A(1-e^{-kd(x,y)})$ can be figured out. Then we obtain

$$L_s(x,y)=L(x,y)-V(x,y)=L_0(x,y)e^{-kd(x,y)} \quad (1)$$

Substituting into Eq. (2), we get

$$L_s(x,y)=[I_0(x,y)e^{-kd(x,y)}]\rho(x,y) \quad (2)$$

We take $I(x,y)=[I_0(x,y)e^{-kd(x,y)}]$ as the illumination of the scene, and the problem is formulated as recovering the reflectance from un-uniform illumination as given in Eq. (3).

$$\rho(x,y)=L_s(x,y)/[I_0(x,y)e^{-kd(x,y)}] \quad (3)$$

According to the illumination-reflectance model in Eq. (2) and Eqs. (2)-(3), we define $L_s(x,y)=I(x,y)\rho(x,y)$, where $\rho(x,y)$ is the reflection coefficient of the target. Based on light absorption/reflection characteristics, we draw the conclusion that for a brightly color object, there must be at least one larger component of the reflection coefficient. So, the high reflectivity of the target image is defined as $\rho(x,y)\to 1$,we can obtain $I(x,y)$ as follw:

$$I(x,y)=\lim_{\rho(x,y)\to 1} L_s(x,y) \quad (4)$$

In the proposed methodology, the largest color component of $L_s(x,y)$ is defined as the highest reflectivity and $I(x,y)$ is preliminarily estimated by

$$I_{mc}(x,y)=\max_{c\in\{R,G,B\}} L_0(x,y) \quad (5)$$

The assumption that $\rho(x,y)\to 1$ cannot be satisfied at every point or at any point. So a filtering algorithm is developed in this paper to obtain a more accurate $I(x,y)$.

In order to get the real appearance of the target, we need to calculate the reflection coefficient $\rho(x,y)$ of the target by Eq. (3), which is of paramount importance to improve the brightness and contrast of the image.

B. Atmosphere Veil Inference

Let $E=V_{dc}(x,y)$, $D=V'_{dc}(x,y)$ be the input image, $V(x,y)$ be the filtered image pixels in the joint spatial-range domain (see Fig.1 (b)). We assign the filtered data via

$$V(x,y)=\sum_{j\in pw}\frac{C}{h_s^2 h_r}k_1\left(\left\|\frac{E-E_j}{h_r}\right\|\right)k_2\left(\left\|\frac{c-c_j}{h_s}\right\|\right)*D_j \quad (6)$$

Where pw is the windows for calculating $V(x,y)$, c is the spatial part, c_j is defined as the position surrounding (x,y) within pw. E_j is defined as the range of the point c_j, k_1, k_2 is the common profile of the kernel used in both domains, h_s and h_r are the employed kernel bandwidths, and C is the corresponding normalization constant. Thus, the bandwidth $h=(h_s,h_r)$ is the only parameter to control the size of the kernel.

According to Eq. (1), the illumination veil function $I(x,y)$ should be solved to get the restored images. As discussed above, the basic property of illumination is smoothness in a local area, and $I(x,y)$ should be both relatively smooth and capable of maintaining the edge details of the scene. Therefore, the cross bilateral filter match well with the problem given above. Therefore, we propose a new method to get $I(x,y)$ and directly provide a fine estimation of the illumination.

In order to get an accurate distribution of the illumination veil, we do some operation on $I_{mc}(x,y)$. In this paper, we perform morphological closing on the $I_{mc}(x,y)$ image with the structuring element. The radius of the structuring element, which is typically defined as $r=\min[w,h]/10$ (w,h are width and height of the input image respectively), can be dynamically adjusted. Additionally, the output of grayscale closing operation on the image $I_{mc}(x,y)$ is defined as $I'_{mc}(x,y)$.

According to Eq. (6), $E=I_{mc}(x,y)$, $D=I'_{mc}(x,y)$. The assignment specifies that the filtered data at the spatial location (x,y) have the range component of the point in $I'_{max}(x,y)$. $I(x,y)$ is given in Fig.1 (d).

C. Scene Restoration

As discussed above, the procedures of the proposed algorithm are given as follows:

1) Input the degraded image $L(x,y)$ with RGB channels.

2) According to R, G, and B channels at each pixel location, preliminarily estimate atmosphere veil $V(x,y)$ by Eq. (5).

3) Refine $V(x,y)$ using joint bilateral filtering on $V_{dc}(x,y)$.

4) Subtract $V(x,y)$ from the mixture $L(x,y)$ to end up with residual image $L_s(x,y)$.

5) According to R, G, and B channels at each pixel location of $L_s(x,y)$, preliminarily estimate illumination veil by Eq. (5).

6) Get $\rho(x,y)$ of the target using $L_s(x,y)/I(x,y)$ as in Eq.(8) and truncate it to the region of [0 1].

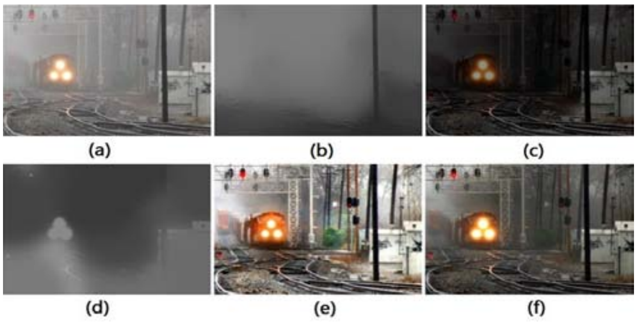


Fig. 1 Restored image 'train' by the proposed algorithm.

(a) Hazy image (b) Atmosphere veil of the input image (c) Result of the residual image (d) Illumination veil of the residual image(e) Restored image by the proposed method in Sec.3.3 (f) Restored result by He et al[4].

As we can see in Fig.1 (e), the halos and block artifacts are suppressed, and the restored image is clearer and brighter than that of He [4].

D. Discussion about non-uniform illumination images

If k=0, then they will be the same model. So, the proposed algorithm can work in non-uniform illumination images to eliminate the affection of the scene light as shown in Fig.1 (e). But to simplify the algorithm, steps 2, 3 and 4 can be ignored.

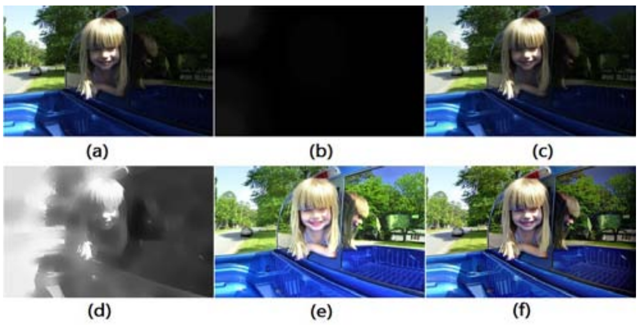


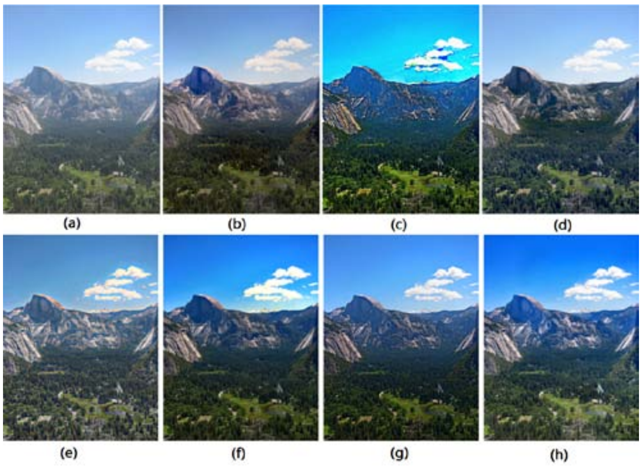
Fig. 2 Restored image 'girl' by proposed algorithm.

(a) Un-uniform illumination image (b) Atmosphere veil of the input image (c) Result of the residual image (d) Illumination veil of the residual image(e) Restored image from the proposed method (f) Restored result by NASA[12]

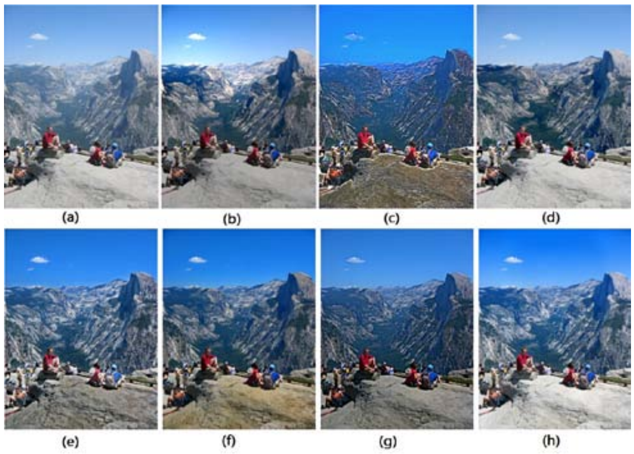
III. EXPERIMENTS

In this paper, we define C_{gain} as the ration of contrast between the restored image and the original image. High values of e , $\overline{r}$, C_{gain} and low values of Σ indicate better performance of the algorithm[15]. To quantitatively assess and rate these state-of-the-art algorithms, we compute four indicators e, $\overline{r}$, Σ and C_{gain} and compare two gray level images: the input image and the restored image.

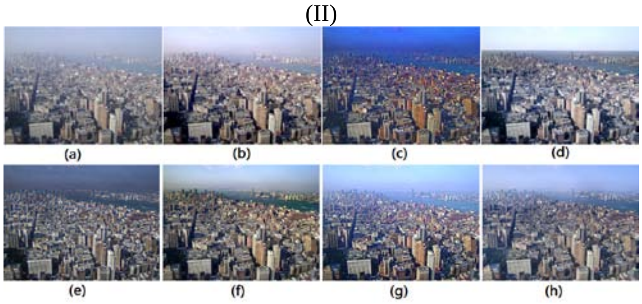
All simulations have been done in MATLAB 7.8.0 environment. Results for the four indicators are shown in Table1. For Fig.3, according to the contrast gain C_{gain} ,the results show that Fattal et al.' and Kopf et al.' algorithm show better performance than other existing algorithms. The proposed algorithm performs well in terms of Σ values. According to the gradient ratio $\overline{r}$, the proposed algorithm gives satisfactory results and shows good performance in indicators e too.



(I)



(II)



(III)

Fig.3 Comparison of qualitative performance algorithm and state-of-the-art algorithms of (I)'y01'(II)'y16'(III) 'ny17'.

(a) Original hazy image. (b) Fattal et al.'s algorithm. (c) Tan et al.'s algorithm. (d) Koef et al.'s algorithm. (e) Tarel et al.'s algorithm. (f)He et al.'s algorithm. (g) A.K. et al.' algorithm. (h) Proposed algorithm.

TABLE I. PRODUCED BY PROPOSED ALGORITHM AND COMPETING METHODS

image	**Y01**				**Y16**				**Ny17**			
Algorithm	e	$\overline{r}$	Σ	C_{gain}	e	$\overline{r}$	Σ	C_{gain}	e	$\overline{r}$	Σ	C_{gain}
Fattal'08[2]	0.0864	1.2152	0.0012	1.1540	0.0583	1.2033	0.0032	1.2458	-0.1061	1.5346	0.0202	1.4139
Tan'08[1]	0.1219	2.2283	0.0039	1.0209	-0.0165	2.0602	0.0045	0.9023	-0.0412	2.1900	0.0077	0.9101
Kopf.'08[5]	0.0947	1.6362	0.0002	1.3088	0.0009	1.3456	0.0028	1.3732	0.0169	1.6136	0.0136	1.5238
Tarel'09[3]	0.2092	1.9903	0.0000	0.8272	0.2406	1.9583	0.0000	0.9218	0.1104	1.7057	0.0000	0.8375
He et al.'09[4]	0.1426	1.3134	0.0101	0.8688	0.1314	1.3674	0.0019	0.9052	0.0232	1.6297	0.0023	1.3204
A.K.'12[8]	0.2532	1.4244	0.0000	1.0551	0.1632	1.4937	0.0002	0.9849	0.2456	2.1832	0.0036	1.4360
Proposed alg.	0.1605	1.5955	0.0017	0.7879	0.1062	1.4015	0.0004	1.2635	0.0372	1.3173	0.0004	1.1157

IV. CONCLUSION

To improve the efficiency of the physical model based single image restoring algorithm, two major factors, atmospheric veil and illumination veil, which affect the effects of the restored images are discussed in details in this paper. The main contribution of the paper is the development of a unified dehazing approach for hazy and un-illumination images. By the cross bilateral filtering, a scene restoration scheme was proposed that produced good color rendition even for severe gray-world violations. This may reflect some underlying principles in the neural computations of consciousness, perhaps, even the visual representation of lightness and color.

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