Restoring Degradation of Hazy Image in HSI Color Space

*Bui, Minh-Trung ** Kim, Won-Ha
Kyung Hee University
*minhtrung@khu.ac.kr

Abstract

Haze is an extreme reason of the reduction of contrast when capturing image in the outdoor. Recently, there are several single image dehazing techniques, but they are not robust in dynamic variations of natural environment caused by the thickness, coverage of haze and appearance of sunlight. In this paper, we propose an effective and robust method to restore degradation of hazy image. Compare with conventional methods, our proposal have better performance and computation time.

1. Introduction

Digital image is hazed when capturing in the scattering-existed scene (e.g. near ocean, aerial image). Hazy natural form dues to atmosphere absorption such as haze, fog, and smoke. The received image at the camera is the result of blending the incoming light and airlight [1]. Haze is not only an extremely reason of degradation of visibility, but also reason of performance degradation of computer vision system. For example, in pedestrian detection system, the false positives per frame are significant increased when implementing in the scattering-exist environment. To enhance the quality of hazed image, there are two ways: (i) image enhancement based on visibility enhancement processing without knowledge of hazy image criteria, (ii) image restoration based on dichromatic model of hazy image. In the first category, there are varieties of classical methods such as histogram equalization, holomorphic filter, wavelet transform, Retinex algorithm. The advantage of these methods is globally able to apply in the wide scene without any assumption, but these methods just can enhance visibility lightly. With the second approach, the physics-based formation of hazy image must be described efficiently. The degradation model widely used is derived in [1-4]. The challenger of this model is to provide the estimation of unknown atmospheric airlight and unknown depth map of image effectively. Recently, dark channel prior (DCP) [1] and median dark channel prior (MDCP) [2] are the most attracting methods for airlight and transmission estimating, but still there are some constrains.

In this paper, we propose a novel human perception-based dehazing for single image. The hazed image has the following degradation: lost details, low contrast and wrong fidelity of color. Wrong fidelity of color includes shifted color and degradation of purity affected by light source. According to this reason, hue component (H) is due to term of color constancy. Color constancy is the ability of recognize colors of objects independent of the color of the light source [5]. After removing effect of light source color, airlight becomes achromatic and color of image (H) should be retained in the following subsequence steps. With I component, a method with purpose of enhancing luminance and removing artifact is also proposed in this term. With S component, we propose a method to recover purity of image depending on transmission map. Compare with conventional methods, our proposal has most efficiency in computation time, accurate estimation, better luminance, and robust with large variants of scattering scene.

2. Dichromatic model and related works

In this section, we will analysis and discuss about two recently effective methods for single image dehazing based on dichromatic model called DCP and MDCP. Both of these methods used the observation of statistical property of outdoor image to estimate the unknown variables. In [1], [2], [3], and [4], dichromatic model of hazed image is given as follows:

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

Where x ∈ Ω, Ω is the set of all position of pixels in image, $I^c(x)$is hazed image, $J^c(x)$is haze-free image, A^c is atmospheric airlight, and $t(x)$) is transmission map. To recover the haze-free image, estimated airlight and transmission are chosen as real airlight and transmission. This task is totally challenge in single image, because there is no information of depth can be retrieved from a single image.

In some literatures such as [1], [3], airlight is the value of pixels in the most-opaque region, so atmospheric airlight has color $A^c = \{A^r, A^g, A^b\}$. In the Tan's work [3], the brightest pixels are assumed as airligtA^c. This method is accurate if luminance sources are ignored. This condition is matched where the weather is overcast, but it is wrong in case of sunlight-existing. Unfortunately, we cannot ignore the effect of sunlight, so in [1] author propose the new airlight estimation method using DCP. First, he picks top 0.1 percent brightest pixels in the dark channel. Among these pixels, the pixels with highest intensity in the input image I^c are selected as atmospheric airlight A^c. This method is more robust than Tan's method, but it fails in the case of very influential sunlight [1].

In proposal of DCP, He *et al.* observe dark property of most of outdoor haze-free image. They collect randomly 5000 images from Flickr.com users and observes that at least one component of pixel's value has small gray-scale. Continuing, they propose the novel term called dark channel given as follows:

$$J^{dark}(x) = w * \min_{x\in\omega(x)}\left(\min_{c\in\{r,g,b\}}(J^c(x))\right) \quad (2)$$

Using this property and some derivations, transmission is estimated as follows:

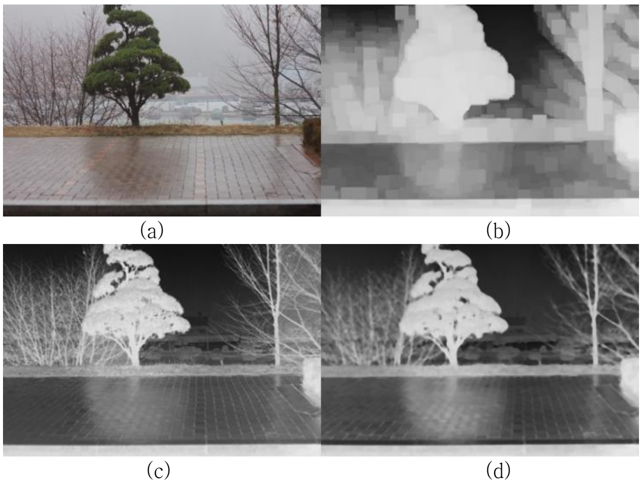

Fig. 1. (a) Hazy image, (b) DCP-based estimated transmission $\tilde{t}(x)$ (c) Matted version of (a) assumed as transmission $t(x)$ (d) MDCP-based estimated transmission

$$\tilde{t}(x) = 1 - w * \min_{x\in\omega(x)}\left(\min_{c\in\{r,g,b\}}\left(\frac{I^c(x)}{A}\right)\right) \quad (3)$$

Where $\tilde{t}(x) = \min_{x\in\omega(x)}(t(x))$

Cause $\tilde{t}(x)$ is the minimum filtered version of transmission $t(x)$, then it has many block showed in figure 1b. To archive complete transmission map, matting step is needed. Detail of matting step is described in [1], [8]. Figure 1c is the matted version of figure 1b and assumed as transmission maps of hazed channel.

DCP gives the strong observation of outdoor image, but somehow there exist some errors in specific cases. Matting step makes transmission map of DCP is more detail and accurate, but it takes a lot of computation and makes method impractical in real-time application. MDCP is another method less accurate than DCP, but more effective in computation than DCP. Similar with DCP, but instead of using minimum filter for neighboring pixels, Gibson et al use median filter [2]. And they also have the transmission map given as follows:

$$\hat{t}(x) = 1 - w * \underset{x\in\omega(x)}{med}\left(\min_{c\in\{r,g,b\}}\left(\frac{I^c(x)}{A}\right)\right) \quad (4)$$

Where $\hat{t}(x) = \underset{x\in\omega(x)}{med}(t(x))$

Purpose of this substitution is to remove block effect of minimum filter cause of median filter property. According to authors in [2], $\hat{t}(x)$ is assumed as transmission without matting step. Figure 1d shows the estimated transmission by MDCP

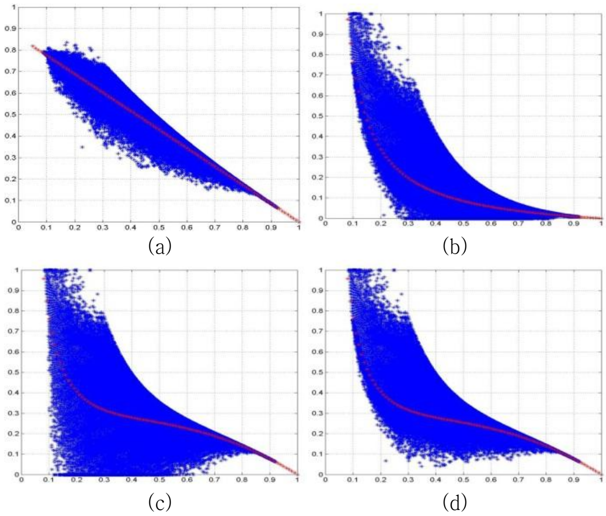

Fig. 2. (a) $I(x)$ vs. $t(x)$, (b) $J(x)$ vs. $t(x)$, (c) enhanced luminance, (d) artifact-removed luminance.

with size of block is 7×7. Although there is no matting step, the estimated transmission map by MDCP in figure 1d is close to the accurate transmission if we assume transmission in figure 1c is correct one. In addition, median filter result is not depending on size of window too much, then window should be small to reduce computation.

3. Proposal of degradation restoring

As discussed in the previous sections, our proposal will be implemented for single image in HSI color space. HSI color space is closer to human perception in which hue (H) refers to the spectral composition of color, saturation (S) defines the purity of colors and (I) refers the brightness of a color or just the luminance value of the color. Converting RGB to HSI and vice versa use the equations in [6]. Our method follows some key points as follows: removing effect of airlight color to retrieve objects of image independent of color of source light; recovering the details hidden by haze with luminance enhancement and without artifact existing; correcting the purity of image to retrieve the fidelity of color.

3.1. Airlight estimation and color correction

In this subsection, color of airlight will be discovered and color-shifting will be removed. According to research presented in [1], haze tends to make gray or bluish hue effect to visibility. In addition, transparent object before

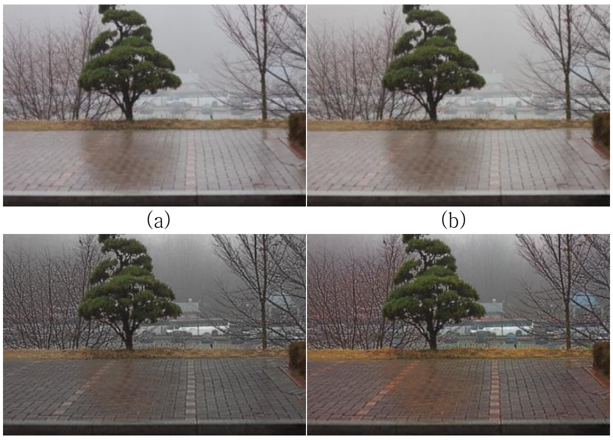

Fig. 3. (a) Hazy image, (b) color−corrected image, (c) luminance−enhanced image, (d) saturation−corrected image.

camera tends to make other effect of color shifting. For instance, camera is usually set up behind the back−shield of car in smart car system, this back−shield tends to make greenish hue effect to visibility. Therefore, result of airlight estimation in previous step is composition of natural haze and color−shifting effect of transparent object. According to [7], color shifting removing equation is given as follows:

$$I_r^c(x) = \frac{1}{\sqrt{3}}\frac{I^c(x)}{A^c} \quad (5)$$

Where A^c is the normalized airlight trieved by using method of DCP. Result of this step can observe when comparing figure 3a and 3b. Hazy image in figure 3a which got bluish hue effect of airlight is corrected color in figure 3b.

Because airlight has no color from now on, A^c becomes A and from equation (1) we have following equation:

$$I(x) = J(x)t(x) + A(1 - t(x)) \quad (6)$$

Where $I(x)$, $J(x)$ are the luminance of hazy and haze−free image, respectively. In conclusion, I channel is degraded same way as RGB channel in achromatic channel. Therefore, we tend to process image dehazing in I channel instead of RGB channel.

3.2. Luminance contrast enhancement

In this subsection, the lost details by degrading luminance are restored. With purpose of reducing computation, we tend to use transmission provided by method of MDCP in equation (4). Furthermore, we observe that luminance and transmission map have the approximate linear relationship as follows:

$$I(x) \cong \frac{A}{w}\big(1 - t(x)\big) = f(t(x)) \quad (7)$$

Figure 2a shows this relationship, in there horizontal axis is the value of transmission, and vertical axis is the value of intensity. The blue points are the figure out of hazed pixels which have transmission $t(x)$ and intensity $I(x$. Red line is approximating functional of relationship. We can see that blue points distributed surround the red line.

Similarly, we discover that dehazed luminance and transmission have non−linear relationship given as follows:

$$J(x) \cong A\left(\frac{1}{w} - 1\right)\left(\frac{1}{t(x)} - 1\right) = g(t(x)) \quad (8)$$

Figure 2b is relationship between transmission and dehazed luminance. The approximating line is nearby the zeros level at the high value of transmission $t(x)$ and this reason makes the dehazed image is darker than original one. Therefore, we propose new line which is similar with $f(t(x)$ at low value of $t(x)$ and similar to $g(t(x)$ at high value of (x) . Formula of proposed line is given as follows:

$$g'\big(t(x)\big) = \big(1 - t(x)\big)g\big(t(x)\big) + t(x)f\big(t(x)\big) \quad (9)$$

This line is adaptive with variant of foggy image. Result of this modification is illustrated in figure 2c. After that, zeros points are removed to eliminate artifact in figure 2d. Result of this step is showed in figure 3c. Details hidden by dense haze is recovered (e.g. braches of trees).

3.3. Saturation correction

In this section, purity of color will be corrected due to its degradation. We observe that in the most−haze region usually in far away, purity of color is poorer than camera−nearby region, because this region got strong effect of haze. To correct this degradation, we tend to put large value of weight for far away region and small weight in the others. Formula of enhanced saturation is given as follow:

$$S_d(x) = w_s(x)S_f(x) \quad (10)$$

Where $S_d(x)$, $S_f(x)$ are saturation of hazy and haze−free image, respectively. Result of this step showed in figure 3d.

4. Conclusion

In this paper, we proposed a novel method for recovering degradation of hazy image with following advantages: recovering degradation of each component in HSI color space without artifact−existing; luminance is adaptively enhanced with variant of scattering−scene. In the future work, we expect to improve step of luminance enhancement in large variant of real environment and integrate all of steps to reduce computation time.

감사의 글

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