Fusion of Dehazing and Retinex using Transmission for Visibility Enhancement

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Abstract: Outdoor images are easily degraded by aerosols such as haze and fog. The existing dehazing methods based on the atmospheric scattering model improve image contrast and color fidelity at the cost of its brightness. We propose a visibility enhancement method by combining dehazing and retinex with the transmission. The proposed method retains both color fidelity and brightness without over saturation.

1 INTRODUCTION

Outdoor images are easily degraded by aerosols, such as haze, fog and dust, since they scatter and absorb the light while they are blended with the ambient light called the airlight. Recently, single image approach without using any other additional information has made progress (Fattal, 2008); (He et al., 2009); (Tan, 2008). He et al. (He et al., 2009) proposed an interesting dark channel prior assuming that in any local region of a haze free outdoor image there is at least one channel of a pixel that is dark. This prior provides easy approximation of the transmission as well as effective estimation of the airlight. However, it improves image contrast and colour fidelity at the cost of image brightness. Therefore, this method mandatorily adopts post-processing, such as gamma correction, a simple brightening by intensity rescaling, and histogram equalization for better visibility, but they often cause oversaturation. The formation of a haze image is described by the atmospheric scattering model (Narasimhan and Nayar, 2003) that consists of two terms: attenuation and airlight. Attenuation describes the way light gets weakened as it traverses from a scene point to the observer. Airlight quantifies the scattered light due to the medium in the atmosphere.

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

where **I** is the observed haze image, **J** is the scene radiance that is the haze free image to restore. **A** is the global atmospheric light, t is called the medium transmission and is the portion of the light that

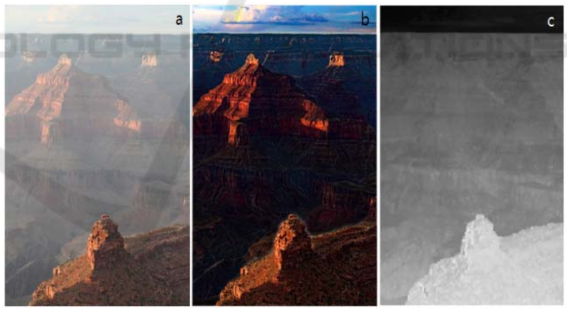

Figure 1: (a) input image, (b) restored image without post-processing (clouds appear, but it becomes dark in the mountains), (c) transmission map (rough depth).

reaches the observer without being scattered, and **x** indicates the position of a pixel. This model assumes that the scene radiance is attenuated exponentially with the scene depth, so the transmission t can be expressed as follows:

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

where d(**x**) is the depth of the scene point from the observer and λ is the wavelength of the medium. β is called the scattering coefficient of the medium. The goal of dehazing is to restore J by estimating t and A from a given input image I. From the equation (1), the attenuation term related to the scene radiance can be computed by subtracting the airlight term from the input image. It indicates that the restored image can lose a small amount of brightness. The restored images look dark compared to the input images shown in Figure 1(a) and Figure 1(b).

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In this paper, we present a new method for both dehazing and visibility enhancement for a given single input image. We achieve this goal by combining the results of dehazing and retinex with the refined dark channel (or the transmission) (He et al., 2009) that approximates a rough depth as shown in Figure 1(c).

2 FUSION OF DEHAZING AND RETINEX

2.1 Dehazing and Retinex

Instead of taking two methods sequentially, we fuse both dehazing and the multi-scale retinex (Jobson et al., 1997) in parallel using the estimated transmission. The dark channel prior assumes that every local patch except for sky region in the haze-free image have at least one color channel near black (near zero). With the dark channel prior, we can compute a coarse transmission map $\tilde{t}(\mathbf{x})$ of a given scene when the airlight is already obtained:

$$\tilde{t}(\mathbf{x}) = 1 - \min_{c \in \{r,g,b\}} \left(\min_{\mathbf{y} \in \Omega(\mathbf{x})} \left(\frac{I^c(y)}{A^c} \right) \right) \tag{3}$$

where I^c is a color channel of I and $\boldsymbol{\Omega}(\mathbf{x})$ is a local patch around $\mathbf{x}$.

To refine the coarse transmission map, the dark channel method adopts the soft matting algorithm (Levin and Weiss, 2006) which is computationally too expensive. Instead of using the soft matting, a cross-bilateral filtering method is adopted by (Zhang et al., 2010) for the refined transmission map $t(\mathbf{x})$. In (He et al., 2009), they can recover the scene radiance simply by solving the inverse of equation (1) with a minor constraint. They restrict the transmission to a low bound t_0 typically being set to 0.1 to preserve a small certain amount of haze in very dense haze region. The final scene radiance is recovered by:

$$\mathbf{J}(\mathbf{x}) = \frac{\mathbf{I}(\mathbf{x}) - \mathbf{A}}{\max(t(\mathbf{x}), t_0)} + \mathbf{A} \tag{4}$$

The airlight can also be computed from the dark channel since the airlight is usually estimated from the most haze-opaque pixels, and the dark channel approximates the haze denseness. In (He et al., 2009), they take the top 0.1% brightest pixels in the dark channel then select the pixels having the highest intensity in the input image among them. In our experiment, we just take the average of the top 0.1% brightest dark channel value for simplicity and robustness.

Since the scene radiance is usually darker than the airlight, the recovered image looks dim with a higher dynamic range as shown in Figure 1(b). Therefore, the existing methods usually adopt post processing such as gamma correction, simple brightening by intensity rescaling, and histogram equalization for better visibility under the risk of over saturation.

Retinex is a theory of color vision that explains how the human visual system extracts reliable information from the world despite of illumination changes. Retinex assumes that the image $\mathbf{I}$ is the product of the illumination $\mathbf{S}$ and surface reflectance $\mathbf{R}$. The goal of the retinex is to decompose the image into the reflectance image and the illumination image. One approach first proposed by Land (Land, 1986), assumes that the illumination value for a pixel is a weighted average of its surroundings, whose weights are given by a Gaussian function. The retinex output is given by:

$$\log \mathbf{R}(\mathbf{x}) = \log \mathbf{I}(\mathbf{x}) - \log[G(\mathbf{x}, \sigma) * \mathbf{I}(\mathbf{x})] \tag{5}$$

where "$*$" denotes the convolution operation, and $G(x, \sigma) = Ke^{-\|x\|/\sigma^2}$ where σ is the scale and K is selected such that $\iint G(x, \sigma)dx = 1$. This model is extended by simply taking the weighted sum of the retinex outputs with different scales of the Gaussian function. This technique is called the multi-scale retinex (Jobson et al., 1997). The multi-scale retinex output is given by:

$$\tilde{\mathbf{R}}(\mathbf{x}) = \sum_{i=1}^{N} \omega_i \cdot (\log \mathbf{I}(\mathbf{x}) - \log[G(\mathbf{x}, \sigma_i) * \mathbf{I}(\mathbf{x})]) \tag{6}$$

where N is the number of scales, and ω_i is the weight typically set to $1/N$ for most applications. The number of scales is usually set to three scales; small, intermediate, and large. This technique significantly enhances the dark region of images usually caused by backlight, which can be achieved by controlling the scale parameter.

2.2 Transmission-based Fusion

The dehazed images often lose their brightness while achieving better contrast and color fidelity. Therefore, the conventional dehazing methods require post-processing that increases the brightness. The retinex algorithm can just be applied as post-processing. However, the images needed to be dehazed have been captured under low lightness, so the sequential combination of dehazing and retinex can make input images be oversaturated with strong noise. We take advantages of dehazing and retinex by combining their results in parallel. The dehazing algorithm has more strength in the pixels at a long distance under the strong influence of haze while the retinex algorithm has strength in the pixels at a relative near distance. This approach requires a depth map. We propose to use the transmission $\mathrm{t}(\mathbf{x})$ the airlight normalized dark channel that effectively approximates the depth of an input image. The proposed method is simply formulated as follow:

$$\mathbf{K}(\mathbf{x}) = (1 - \alpha\, \mathrm{t}(\mathbf{x}))\, \mathbf{J}(\mathbf{x}) + \alpha\, \mathrm{t}(\mathbf{x}) \tilde{\mathbf{R}}(\mathbf{x}) \qquad (7)$$

where α is the combining weight. In our experiment, we usually get visually better results with α=0.8 for higher weight to the dehazing.

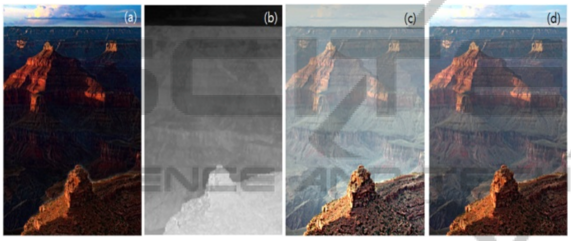

Figure 2: From left to right, dehazing without post-processing, transmission, retinex, and the final result of combining (a) and (c) using (b).

Figure 2 demonstrates the effectiveness of the proposed method. In Figure 2(a) the dehazing has strength in the sky region by recovering the shape and color of the clouds at the cost of losing much brightness. In Figure 2(b) the transmission map achieves reasonable depth estimation of the scene; close object looks bright and distance object looks dark. In Figure 2(c) the retinex achieves a good brightness in the shadow regions of the mountain; however, it fails to recover the sky region. In Figure 2(d) our proposed fusion method takes both advantages of dehazing and retinex.

3 EXPERIMENTS

In Figure 3, we compare the proposed method with respect to post-processing. Our method generates more natural scenery compared to the others that suffer from oversaturation in the middle of the mountain and sky regions. Gamma correction increases brightness of the mountain region but not sufficient. Intensity rescaling fails to recover the correct color in both sky and mountain regions.

Figure 4 compares He's method, retinex, and the proposed method. Our proposed method achieved better visibility in the region of the tree and the boundary of the lake while revealing the building covered by a dense fog in background like (b). Meanwhile the retinex has no effect on removing dense haze at all in this image.

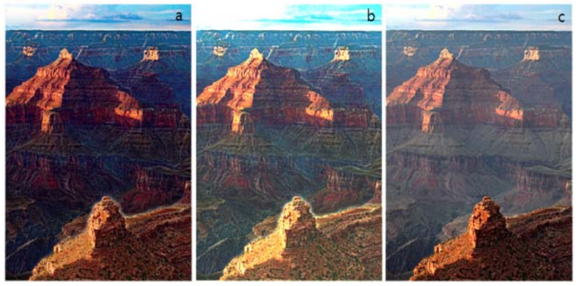

Figure 3: He's result with a: gamma correction, b: intensity rescaling and c: the proposed method.

Figure 4: Visual comparison results. (a) input image, (b) dehazing, (c) retinex, and (d) the proposed method.

4 CONCLUSIONS

In this paper, we proposed to use the transmission map; rough estimation of scene depth, for combining both results of dehazing and retinex to retain the advantages of them. The experimental results demonstrated that our method generated more natural scenery with a proper visibility

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