HAZE AND CONVERGENCE MODELS: EXPERIMENTAL COMPARISON

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ABSTRACT

Bad environmental conditions like bad weather, such as fog and haze, and smoke-filled monitored closed areas, cause a degradation and a loss in contrast and color information in images. Unlike outdoor scenes imaged in a foggy day, an indoor artificial hazy scene can be acquired in controlled conditions, while the clear image is always available when the smoke is dispersed. This can help to investigate models of haze and evaluate dehazing algorithms. Thus, an artificial indoor scene was set up in a closed area with a mean to control the amount of haze within this scene. While a convergence model simulates correctly a small amount of haze, it fails to reproduce the same perceived hazy colors of the real image when haze density is high. This difference becomes obvious when the same dehazing method is applied to both images. Unlike simulated images, colors in real hazy images are resulted from environmental illuminants interference.

1. INTRODUCTION

Outdoor images are usually prone to degradation caused by atmospheric scattering particles. Indoor images captured and handled by monitoring sensors could be as well subject to color and contrast fadeout caused by occasional smoke emission, causing security failure. Many dehazing methods have been proposed to minimize this degradation and to recover original scene contrast [7, 12]. Although several articles have reported the shortage of color fidelity in recovered scenes [4, 9], none of the existing methods has deeply addressed this problem from a color point of view. In order to address this issue, we initiated to depict color shift between original clear image and the dehazed one of a simulated scene based on convergence model [3]. Recently, an artificial indoor hazy scene was installed to see how a real hazy scene could be faithfully represented by simulation.

The principal aim of this paper is to identify the limits that prevent a simulated hazy image formed by the convergence model to represent the same veiled object placed at a constant distance while changing fog density. Convergence model does not include the distance between the object and the camera and the effect of the fog that lies through the line of sight.

The rest of this paper is organized as follows. After briefly introducing dehazing and color convergence models and outlining the previous work in section 2, we describe in section 3 the experimental procedure of hazy images establishment. Experimental results and discussion are given in section 4, and conclusions and future works in section 5.

2. BACKGROUND AND PREVIOUS WORK

2.1 Haze and convergence models

According to D'Zmura *et al.* [1], translation and convergence in CIE xy lead to the perception of transparency. Color constancy revealed in presence of fog can be modelled by convergence model while taking into consideration shift in color and contrast. This was confirmed by asymmetric matching experiments.

Koschmieder [8] established a linear relationship between the luminance reflected by the object and the luminance reaching the observer. This linear relationship is based on the distance between the observer and the object. As Koschmieder stated, the problem of restoring true intensities and color, presents an underlying ambiguity that cannot be analytically solved unless scene depth data is available. The scene depth is equivalent to transmission.

Haze (1) and color transparency (2) are equivalently modelled:

$$I(x) = J(x)t(x) + A_\infty\big(1 - t(x)\big) \quad (1) \qquad b = (1-\alpha)a + \alpha f \quad (2)$$

$I(x)$ is the perceived intensity of the hazed image, $J(x)$ is the scene radiance of the original free-haze image and $t(x)$ is the direct transmission, which represents the non scattered light emanating from the object and is attenuated by the scattering along the line of sight ($t(x) = e^{-\beta d}$, β is the scattering coefficient and d is the scene depth). The airlight corresponds to an object at an infinite distance and it is called atmospheric light A_∞. The airlight $A(1-t(x))$ is the light coming from an illuminant (*i.e.* sun) and scattered by the atmospheric particles towards the camera. In the transparency model, a represents the tristimulus values of a surface; a convergence application leads to new tristimulus values b. f is the target of convergence. α represents the amount of fog covering the surface. Light that reaches the eye from the surface is the sum of the original light emanating from the surface and the light that depends on the chromatic properties of the fog.

2.2 Previous work

Dehazing aims at the inversion of haze model, the automatic evaluation of parameters influences color recovering. In order to qualify this, we initiated previous work by studying how dehazing methods fail to recover accurately original colors of simulated hazy scene. In the previous work [3], we proposed a simulation of haze based on the convergence model. Color shift evaluation was done using this model. Unlike haze model, the transmission of the surface depends only on the amount of covering fog, which is a transparent filter, and it does not depend on the distance between the surface and the camera. We assumed that the effect of this distance is equivalent to α: when alpha increases, this gives the same impression as the distance increases through the haze. According to the convergence model, the simulation consists on embedding haze in CIE XYZ image of GretagMacbeth ColorChecker. We applied the same model to RGB image in order to perform a cross validation with two different spaces basis [3]. The dehazing method Dark Channel Prior (DCP) [6] was applied to recover original image. Thus, we realized by converting color to IPT color space [2] and CIE LUV, that this method boosts the color saturation without altering hue of highly chromatic colors.

3. EXPERIMENTAL SETUP

In order to provide stable basic conditions that simplify the evaluation of dehazing processes, we proceeded by creating controlled indoor hazy scene. This scene was set up in a closed room with a large window that allows a homogenous sunlight to get in, in order to avoid directionality of artificial light. At the back of the calibrated scene, the farthest point to the camera Nikon D7100 (6.9 m), where the covering airlight is considered to have the maximal value, we placed a GretagMacbeth ColorChecker, and we changed consecutively the amount of emitted haze. The smoke machine FOGBURST 1500 was used for haze emission, and the different levels of haze by evacuating progressively the emitted haze. We used also the Konica Minolta CS-2000 spectroradiometer for transmittance measurements of the haze.

The spectra of Figure 2 depict the transmittance of the white patch of each haze level. When the haze veil dominates the image, we can easily notice that transmittance curves represent the light scattered by haze particles adding to it the daylight reflected by the patch. The manner how the transmission intensity evolves through haze levels, we can notice that the luminance of haze density is exponentially evolving. From level 6 the transmittance intensity becomes to reach back and to be closer again to the transmittance spectrum of the clear image. This leads to deduce that the airlight causes the atmosphere to behave like a secondary light source of a different type than the outdoor global illumination.

According to the definition of convergence model parameters, b is the image that is covered by a given level of haze. a is the clear image, which is considered to be the one captured without embedding haze. f represents the tristimulus value of the captured target when it is covered by an opaque haze veil. Finally, α is calculated by inverting the convergence model and choosing the value corresponding to the black patch. We assume that the darkest patch does not reflect the daylight, and that the airlight over this patch is only due to the haze veil. The camera noise is removed by subtracting the tristimulus values of the black patch in clear image from the values of the same patch covered by different haze levels. Equiluminous veil embedded in simulated images where α is constant, is unnatural, and it cannot be represented by such physical veil.

Figure 1 – Our database. The images of the GretagMacbeth ColorChecker taken under different haze levels. From left to right: Level 1; Level 2; Level 3; Level 4; Level 5; Level 6; Level 7; Level 8; Level 9; Clear image.

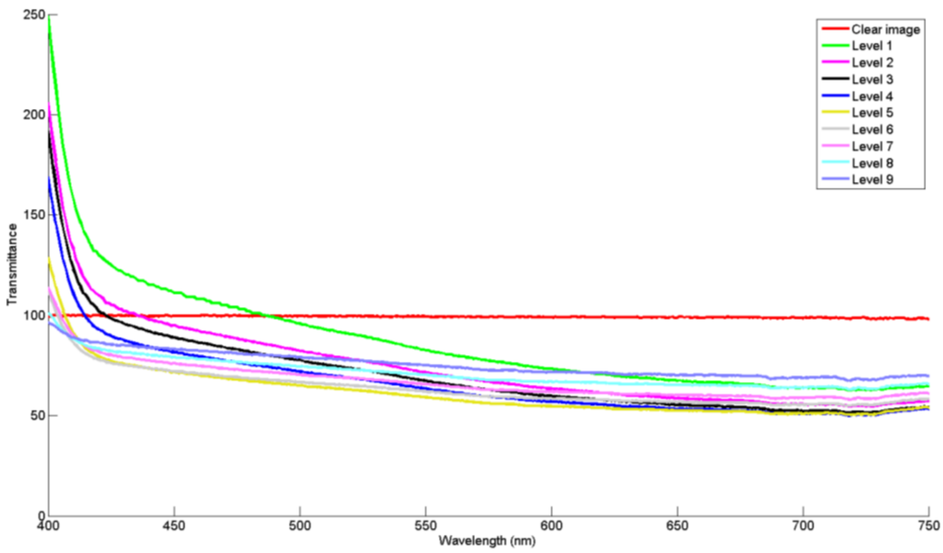

Figure 2 – Transmission curves of the white patch at different haze density levels. We notice that the short wavelength overcome the calibration. According to Rayleigh scattering [11], the strong wavelength dependence of the scattering ($\sim\lambda^{-4}$) means that shorter (blue) wavelengths are scattered more strongly than longer (red) wavelengths.

4. DISCUSSION

Haze that lies between the camera and the ColorChecker target modifies the light that emanates from it and reaches the camera. The light reflected from the target is added to the light scattered by the intervening particles. When the haze density greatly increases and the scattered light overcomes the light reflected by the target, the perceived colors components, hue and saturation, shift from their original values. This is clearly shown in Figure 3, where the simulation succeeds to represent the real scene of level 9 (with a little saturation difference related to the clear black patch) and fails for level 5. Referring to Figure 4, the distributions of points representing the red patch from level 5 to level 2 change between (a) and (b), while other points keep the same relative place between the end points (red and white) with a little shift in saturation (as shown in Figure 3 for Scene Level 9 and Simulated Level 9).

As it is defined above, the direct transmission is the light that reaches the camera without being scattered. Thus, the hue of this light is assumed to be independent of the reflected surface depth. The hue of airlight depends on the particle size distribution and tends to be gray or light blue in the case of haze and fog [11]. According to Figure 4, when the haze veil becomes great, the points placed on the chromaticity diagram of the patches, deviate from the line linking the haze veil color (white point) to the original unveiled color (red point), and they are biased toward blue/green area. Some points are also located outside the area between the red and white points. The deviation rate depends on the patch color, the airlight and the sunlight interference. When the amount of deviation in simulated scenes is smaller, all points representing a given patch at different haze levels remain between the red and white point.

When DCP is applied to Scene Level 5 (Figure 3), it accentuates the veiled colors by enhancing saturation. The recovered colors are totally different from those recovered from the Simulated Level 5, where the target and the veil are colorimetrically independent.

Figure 3 – The first line represents two different levels of scene images and the corresponding simulated images. The second line represents the recovered images by DCP of the first line images. From left to right (first line): Scene Level 9 – Simulated Level 9 – Scene Level 5 – Simulated Level 5. DCP fails to recover accurately the same colors for both images of Level 5 where haze density is high. Unlike the simulated scene, irradiance undergo illuminants interference and scattering effects.

This work confirms the previous conclusions considering that DCP saturates recovered colors. And the way it estimates the airlight and the transmission does not enables it to take into consideration the interference of different illuminants. As the retrieval of these parameters is limited to the pixels' intensities estimation, its mission remains limited to saturation enhancement, and original hues are not accurately recovered (Figure 3). On the other side, when the density of haze is small and the original hue is not altered, a simple adjustment based on convergence model could reinstate original saturation.

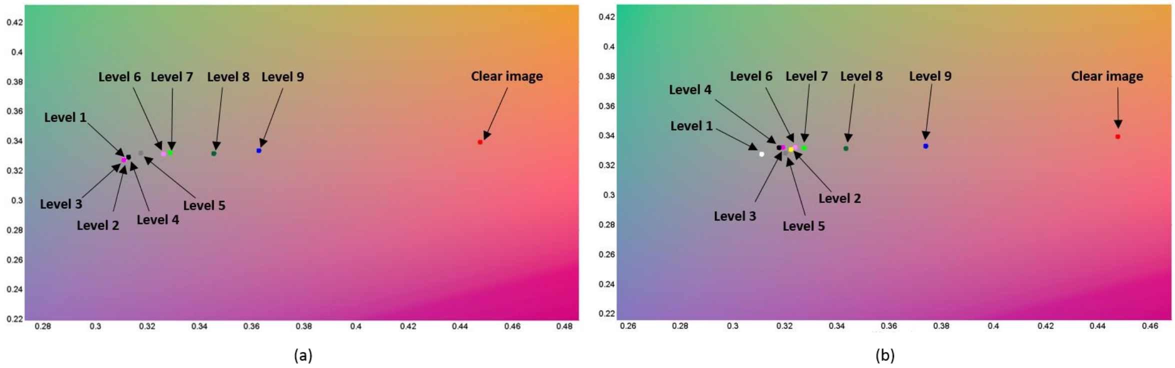

Figure 4 – The chromaticities of different haze levels placed on the chromaticity diagram of the red patch. (a) Real Scene, (b) Simulated Scene. Red: clear image – white: Level 1 – yellow: Level 2 – magenta: Level 3 – black: Level 4 - gray: Level 5 – pink: Level 6 – green: Level 7 – dark green: Level 8 – blue: Level 9. The distributions of points representing the red path from level 5 to level 2 are different between (a) an (b), while other points keep the same relative place between the end points (red and white) with a little shift in saturation.

5. CONCLUSIONS AND FUTURE WORKS

In this article we study the similarities between a simulated hazy image created by a convergence model and a real hazy scene. Physical luminous interaction modifies the perceived scene, while colors in the simulated image maintain their hue information and only their saturation component shifts between the original color (saturated), and the haze color (unsaturated). Convergence model fails to stand for hazy image when the density of haze becomes considerably high. Dehazing methods like DCP, aim just to remove the covered veil and to recover the color as it is not completely hidden, without taking into consideration the interaction of different phenomenon. Thus, a pre-processing aiming to adjust hue color, and a post-processing based on convergence model for saturation adjustments.

Future works shall focus on the validation of the color correction on dehazed images. We intend also to investigate the possibility to extend color-based image dehazing methods to multispectral-based image. Calibrated hazy images database should evidently considered as a benchmarking tool of colorimetric issues that are related to dehazing methods.

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