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The impact of noise estimation on dehazing

Jessica El Khoury

ImViA Laboratory, Université de Bourgogne Franche-Comté, Dijon, France

Corresponding author: jessica.el-khoury@u-bourgogne.fr

Presenting author: Jessica El Khoury

ABSTRACT

Under haze or fog, the quality of the images is degraded due to the atmosphere, causing the details of the images to be difficult to identify by observers and computer vision systems. Such images contain noise, which is mainly due either to environment (extrinsic noise) or sensor (intrinsic noise). As the transmission of light coming from the scenes' objects is exponentially attenuated and comes quickly down to zero in presence of haze, the noise is greatly amplified at high haze densities and long distances. In order to investigate the importance of the accurate estimation and the removal of noise from hazy images, we used the CHIC (Color Hazy Image for Comparison) database, which provides, for a given scene, the haze-free image and a set of images with different haze densities. For each scene, several parameters are available like the distance from the camera of known objects such as Macbeth Color Checkers, their radiance, and the haze level through transmittance. At two levels of haze, we added some Gaussian noise. We first applied dehazing without considering the induced noise. Later, we applied it with including the accurate value of added noise and finally by using biased values. This study shows the importance to estimate as accurately as possible the noise in order to remove it and guarantee a high quality and a good recovery of images' features after dehazing.

Keywords: *dehazing, denoising, image quality, color*

INTRODUCTION

Bad visibility can be caused by the presence of particles in the atmosphere. The nature of these particles is determined by the causing phenomenon: it could be haze, fog, smoke or pollution. Although these phenomena have different natures, they all degrade severely the atmospheric visibility, depending on their density.

To deal with these phenomena produced either by human activities or nature, a wide number of dehazing approaches have been developed in the last decade to increase visibility. Earlier methods favored multiple data acquisition to break down the ill-posedness of the formulation of visibility degradation (Equation 1). Besides the RGB hazy image, the additional data could be a near infrared image, a differently polarized image or a depth map (Srinivasa et al. 2003; Schechner et al. 2003; Kopf et al. 2008). With the multiplication of computer vision applications for driving assistance, air navigation and outdoor surveillance, researchers have been focusing on single image dehazing for several years. This is because single image dehazing requires only the degraded image provided by a simple and an affordable imaging system.

Several dehazing approaches are currently available. In some of them, haze is considered as a contrast-reducing veil. Thus, classical contrast enhancement methods have been applied on hazy images (Xu et al. 2009). Other approaches consider the physical aspect of haze, through the estimation of the physical parameters of the haze model. The estimation of parameters is usually based on hypotheses made upon observations on hazy images. The most known dehazing approach is based on dark channel prior. It mostly considers daytime outdoor images that have some very dark pixels, which provide a good

estimate of haze (He et al. 2010). The methods, which are recently proposed, mostly adopt machine-learning approaches (Cai et al. 2016).

Among these numerous approaches, only a few methods consider the removal of noise (Matlin and Milanfar 2012; Liu et al. 2017), which is inevitable in natural images and when it is ignored, it degrades remarkably the quality of dehazed images.

In the following sections, we introduce the noise and its modelling in hazy images. We then describe the experiment we performed to demonstrate how the bad estimate of noise in hazy images impact the image quality after dehazing and the recovery of colors. We conclude the article by a brief discussion of the results.

NOISE IN HAZY IMAGES

According to Kochmieder (Koschmieder 1924), the formation of hazy images can be modelled by the following equation:

$$I(x) = J(x)t(x) + A_{\infty}(1 - t(x)) \quad (1)$$

where $I(x)$ is the hazy image captured by the camera's sensor. It is formed by the scene radiance $J(x)$ and the atmospheric light A_{∞} weighted by the light transmission factor $t(x)$, which depends on the scene depth d and the scattering coefficient β of the haze, such that $t(x) = e^{-\beta d(x)}$.

The equation 1 represents the optimistic model of hazy images free of noise. However, the imperfection of the environment conditions and the sensors induces noise $n(x)$ in digital images, which is usually amplified through dehazing. $n(x)$ is the noise contribution, assumed to be independent and identically distributed with zero mean and variance δ^2 :

$$I(x) = J(x)t(x) + A_{\infty}(1 - t(x)) + n(x) \quad (2)$$

There are two main approaches to deal with haze and noise. The first one consists of dehazing followed by denoising as two separate processing steps. The second one is the application of dehazing and denoising simultaneously. Noise can be over-estimated or under-estimated, depending on the applied approach. When it is over-estimated, this means the hazy image will be over-denoised and therefore smoother. This induces the loss of fine useful details such as edges and textures. However, it produces results of better quality than the under-estimation of noise, since the remaining amount of noise is noticeably amplified after dehazing (Matlin and Milanfar 2012).

EXPERIMENTAL SETUP

In order to show how much the quality and the recovered colors of dehazed images are affected when the noise is ignored or not accurately estimated, we used, as shown in figure 1, two images of the same scene with two densities of haze, H1 and H2, from CHIC database (El Khoury et al. 2016). From the entire image, we only considered the Macbeth ColorChecker placed at the back of the scene, since the parameters forming equation 1 are provided in the database at this position. To both images cropped from H1 and H2, we added some gaussian noise with $\delta = 0.01$ (figure 2).

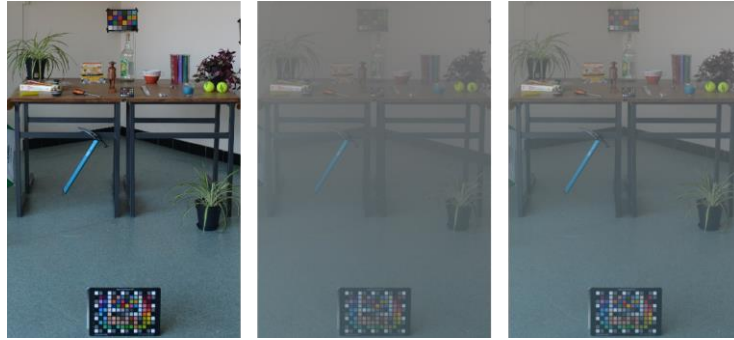


Figure 1: Images taken from CHIC database. From left to right: Haze-free image, hazy image H1, hazy image H2.

To investigate the importance of estimating accurately the noise in images, at two levels of haze H1 and H2, we performed dehazing by inverting the equation 1 and calculating $J(x)$ through four ways: in the first we dehazed the image without considering noise. In the second, while dehazing we removed the accurate amount of added noise. In the third and fourth, the dehazing was performed without any accurate estimation of noise by using slightly higher and lower values of the real δ denoted by δ_e . The corresponding results are shown in Figures 3 and 4.

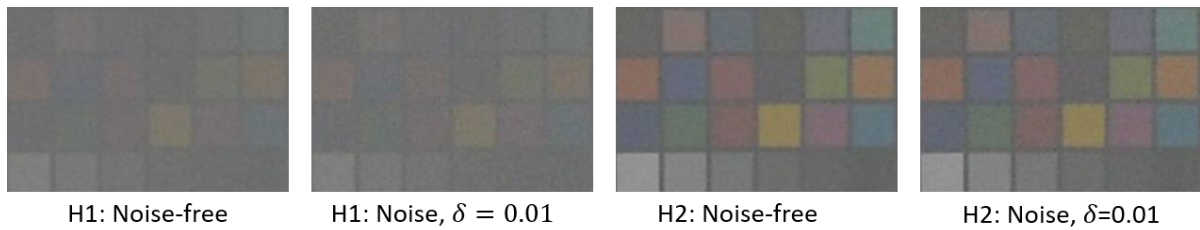


Figure 2: Macbeth ColorChecker cropped from images H1 and H2.

To quantify the quality of images after the application of dehazing and denoising, we calculated the scores of the classical metrics that are often used to assess the performance of dehazing methods when the haze-free image is available, PSNR and SSIM (Wang et al. 2004). A higher quality is indicated by a higher value of PSNR and a SSIM value closer to 1. We also calculated the color difference parameter ΔE_{ab} as an indicator to report the inaccuracy in the recovery of colors. All these indicators have been calculated between the dehazed images and the haze-free image considered as the reference image with optimal quality.

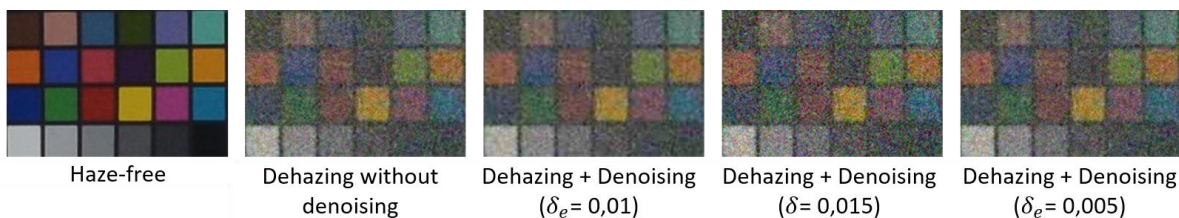


Figure 3: The haze-free and the denoised images of the Macbeth ColorChecker placed at the back of the hazy image H1.

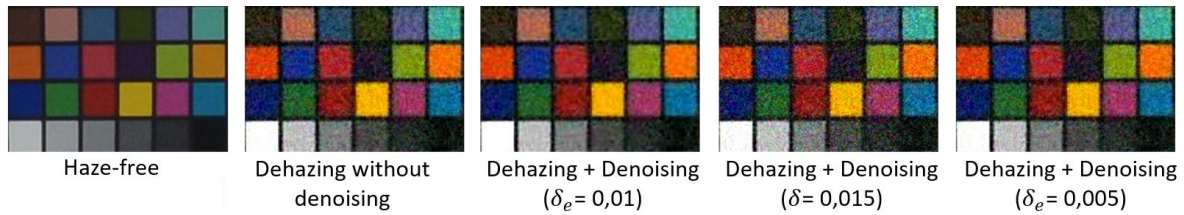


Figure 4: The haze-free and the denoised images of the Macbeth ColorChecker placed at the back of the hazy image H2.

DISCUSSION

Considering the visual assessment of the images presented in Figures 3 and 4, the dehazed images of H1, are strikingly affected by noise. With the same quantity of noise, the quality of these images is more affected than in the images of H2, which has a lower density of haze. This observation is in line with the scores of indicators in Table 1. PSNR and SSIM indicate that all dehazed images of H2 have a higher quality than the corresponding images of H1. Likewise, ΔE_{ab} underlines a higher similarity between dehazed images and the haze-free image.

According to the scores in Table 1, the accurate estimate of noise is always beneficial no matter what the level of haze is. Contrary to what might be expected, ignoring completely the induced noise seems to provide a better outcome than when it is inaccurately estimated. This is valid for both levels of haze either when the noise is overestimated or underestimated. However, we should mention that when δ_e is lower than the real δ , the resulting image is smoother as some noise are eliminated. Therefore, the dehazed image in this case is closer to the reference image.

	Dehazing without denoising			Dehazing + Denoising ($\delta = 0.01$)			Dehazing + Denoising ($\delta_e = 0.015$)			Dehazing + Denoising ($\delta_e = 0.005$)		
	PSNR	SSIM	ΔE_{ab}	PSNR	SSIM	ΔE_{ab}	PSNR	SSIM	ΔE_{ab}	PSNR	SSIM	ΔE_{ab}
H1	16.89	0.40	25.32	17.64	0.52	21.15	15.67	0.30	31.88	16.74	0.39	26.21
H2	19.06	0.67	18.55	19.96	0.78	13.35	17.65	0.56	25.11	18.90	0.65	19.39

Table 1: The values of PSNR, SSIM and ΔE_{ab} of the images presented in Figures 3 and 4.

CONCLUSIONS

In this paper, we have investigated the importance of noise estimation accuracy and how this impacts the features of images. For this, we used some quality and color difference metrics. This study showed that when the noise is not accurately estimated, it is better to ignore it. And when it is accurately estimated, the resulting image has the highest quality.

To the best of our knowledge, the quantification of color and quality degradation caused by the lack of the accuracy in noise estimation, has been timidly addressed. Through this study, we pointed out the importance to stimulate the awareness of researchers of the need to include denoising as a mandatory treatment into dehazing and to focus on the proper modelling of noise that will guarantee an accurate estimation of it.

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