A Single Image Dehazing Method Based on Adaptive Gamma Correction

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***Abstract*— Image dehazing is an important task in control systems of autonomous vehicles. It is necessary to increase accuracy and performance of road obstacles recognition. In this paper, we propose a single image dehazing method based on adaptive gamma correction (DAGC). The DAGC method processes haze on the Value band of the HSV color space by using the Gamma-correction with estimating the adaptive parameter based on the weighting cumulative density function. Otherwise, it also improves the Saturation band. In the experiments, we tested the DAGC method on the dehazing dataset of TAU and compare with other similar dehazing methods. The results showed that, the proposed method outperformed other methods.**

Keywords—Dehazing, Defogging, Image Restoration, Image Processing, Gamma Correction, Adaptive Gamma Correction.

I. Introduction

Today, there are many studies focusing on autonomous vehicles. This research is becoming a trend in the fourth industry revolution and it has a variety of important applications in our life. The topics of automation and control for self-driving cars require contributions of various science fields. One of the important tasks is to preprocess the input data. The input data is usually captured by camera and various sensors. The quality of the input image captured by camera is very important to improve accuracy and performance of the system. Autonomous vehicles usually face many unfavorable factors of weather and environment. Haze [1] is a one from them. Haze reduces visibility, it can cause wrong detection and the system can work incorrectly. Hence, haze removal is a necessary task. It belongs to the group of the image restoration problems [2].

The dehazing problem not only focuses on removing fog, but also on other factors such as dust, smoke etc. There are two effects on the input image that haze can cause: reduction of the signal of the scene and addition of ambient light [3].

There are several approaches to remove haze: capture various images in different weather conditions [4], or capture two images with various polarization states [5] and single image dehazing [3, 1, 6, 7, 8]. In this paper, we only focus on the single image dehazing.

In recent years, He et al. developed a single image dehazing method based on dark channel prior [7]. Zhang et al. proposed an effective dehazing method by combining Retinex and the Haar wavelet transform [1]. Another well-known single dehazing method was proposed by Dubok et al. The Dubok method [6] was developed by using image entropy and information fidelity.

Our goal to solve the dehazing problem is to enhance contrast of the Value band of the input image in the HSV (Hue-Saturation-Value) color space [9] by using the Gamma-correction with estimating the adaptive parameter and to improve the Saturation band. We call the proposed method to be DAGC (Dehaze by Adaptive Gamma-correction).

For experiments, we use the hazy dataset of TAU. We implement the DAGC method, the dehazing method by the dark channel [7] and the Dubok method [6] to remove haze. In order to compare the image quality after dehazing, we utilize the Natural Index Quality Evaluation (NIQE) metric [10].

Our work is structured as follows. Section II describes the dehazing problem, introduce definitions and notions; and presents the DAGC method. Section III presents experiments, comparison and discussion. Finally, Section IV concludes.

II. Dehazing Problem and Proposed Method

A. Dehazing problem

Let $[u_{ij}]_{m\times n}, [v_{ij}]_{m\times n}$ be a clean image (ground truth, haze-free image) and a hazy image, respectively, where m, n are number of pixels by width and by height of each image. The hazy image formation can be modelled as follows [7, 6, 5]:

$$v_{ij} = t_{ij}u_{ij} + (1 - t_{ij})A_{ij},$$

where A_{ij} is intensity of ambient light for each pixel, and $0 \le t_{ij} \le 1$ is transmission along the camera ray for each pixel.

B. Definitions and Notions

Definition 1. Suppose that ℓ be an integer number denoting gray value of pixels, $\ell \in [u_{min}, u_{max}]$, where u_{min}, u_{max} are the minimum and the maximum gray values of an image, respectively. The probability density function for a pixel acquiring gray level ℓ can be approximated by:

$$\wp(\ell) = \frac{n_\ell}{mn},$$

where n_ℓ is number of pixels of which gray value is ℓ. We denote $\wp_{max} = \max_\ell \wp(\ell)$, $\wp_{min} = \min_\ell \wp(\ell)$.

Definition 2. We call a function:

$$c(\ell) = \sum_{k=0}^{\ell} \wp(k)$$

to be a cumulative density function for a gray level ℓ.

Definition 3. The weighting distribution function is defined as follows:

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$$\mathbb{p}(\ell) = \wp_{max}\left(\frac{\wp(\ell) - \wp_{min}}{\wp_{max} - \wp_{min}}\right)^{\alpha},$$

where $\alpha > 0$ is an adjusted parameter.

Definition 4. Suppose that

$$\mathbb{p}_{\Sigma} = \sum_{k=0}^{u_{max}} \mathbb{p}(k).$$

We call the function:

$$\mathbb{c}(\ell) = \frac{1}{\mathbb{p}_{\Sigma}} \sum_{k=0}^{\ell} \mathbb{p}(k)$$

the weighting cumulative density function for a gray level ℓ.

Definition 5. A Gamma-correction [11, 12, 13, 14] is a transform defined as follows:

$$\mathcal{G}(\ell) = u_{max}\left(\frac{\ell}{u_{max}}\right)^{\gamma},$$

where $\gamma > 0$ is an adaptive parameter.

C. Proposed Dehazing Method

The goal of the proposed method is to enhance contrast of the Value band of the input image of the HSV (Hue-Saturation-Value) color space by the Gamma-correction. In our research, we realized that haze mainly focuses on the Value band of the HSV color model.

An adaptive Gamma-correction [11, 14] is a combination of the Gamma-correction with estimating the adaptive parameter γ. In this paper, we choose value of γ based on the weighting cumulative density function: $\gamma = 1 - \mathbb{c}(\ell)$.

The single image dehazing method with adaptive Gamma-correction is presented in Algorithm 1. Let us consider how the algorithm works. We do not remove haze directly on the image of the RGB color space, because it is not effective. Haze will distribute on all channels of the RGB color space with various densities. Therefore, if we dehaze directly on each channel of the RGB color space, it will cause artificial blocks. When transforming to the HSV color space, the haze will mainly focus on the Value band. Hence, we utilize the adaptive Gamma-correction to remove haze. We do not process the Hue band. We only process the Saturation band and the Value band. For the Saturation band, we increase its value by β. For the Value band, we apply the Gamma-correction with adaptive parameter based on the weighting cumulative density function. Finally, we transform the image of the HSV color space back to the RGB color space.

Complexity of the proposed algorithm is $O(m \times n \times u_{max})$. We must notice that, we only process the Saturation band by the adaptive Gamma-correction and if this band is an 8-bit image (almost images are stored in 8-bits depth), i.e., $u_{max} = 255$, the complexity will be $O(255 \times m \times n)$, with m, n are sizes by pixel of the width and the height of an image.

Algorithm 1. Single Image Dehazing Method with Adaptive Gamma-Correction (DAGC).

Input: The hazy image v.
Output: The dehazed image u.

- Initialize $\alpha \coloneqq 0.75,\ \beta \coloneqq 0.015$.
- Transform v to the HSV color space: $v_{HSV} \coloneqq HSV(v)$.
- Separate all bands: $v_{HSV} \xrightarrow{separate} (v_H, v_S, v_V)$.
- For each pixel (i, j), compute:

$$(u_H)_{ij} \coloneqq (v_H)_{ij},$$

$$(u_S)_{ij} \coloneqq (v_S)_{ij} + \beta,$$

$$\gamma_{ij} \coloneqq 1 - \mathbb{c}\left((v_V)_{ij}\right),$$

$$(u_V)_{ij} \coloneqq u_{max}\left(\frac{(v_V)_{ij}}{u_{max}}\right)^{\gamma_{ij}}.$$

- Combine all bands: $u_{HSV} \xleftarrow{combine} (u_H, u_S, u_V)$.
- Transform u_{HSV} to the RGB color space: $u \coloneqq RGB(u_{HSV})$.

III. Experimental Results and Discussions

In the DAGC method, we fixed parameters α by 0.75 and β by 0.015. Programs implementation of other dehazing methods such as the dehazing method by the dark channel, the dehazing method by Dubok el al., are given by the Authors. We keep all parameters as default.

A. Image Restoration Quality Assessment Metrics

In order to assess image quality after dehazing, we use the blind image quality assessment. The well-known blink image quality assessment metric is the Natural Index Quality Evaluation (NIQE) [10, 8]. NIQE use a default model computed from natural scenes as the ground truth. Hence, NIQE will compare the input image with the default model to evaluate score. NIQE score is computed by the following steps:

- From the input natural image, we build a natural statistical scene.
- Statistical features extraction by using corpus of the natural image.
- Mapping features extraction to a score. This score reflects image quality and it is called to be NIQE index.

The smaller value of the NIQE, the better perceptual quality. In the MATLAB computing system with the Image Processing Toolbox, we can use the built-in *niqe* function to evaluate the NIQE score.

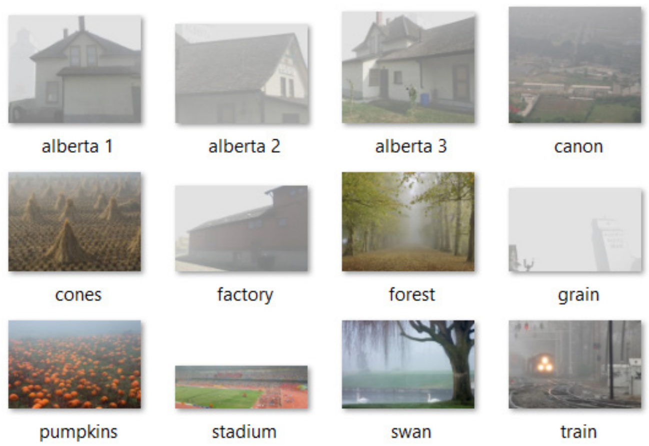

Fig. 1. Several selected hazy images.

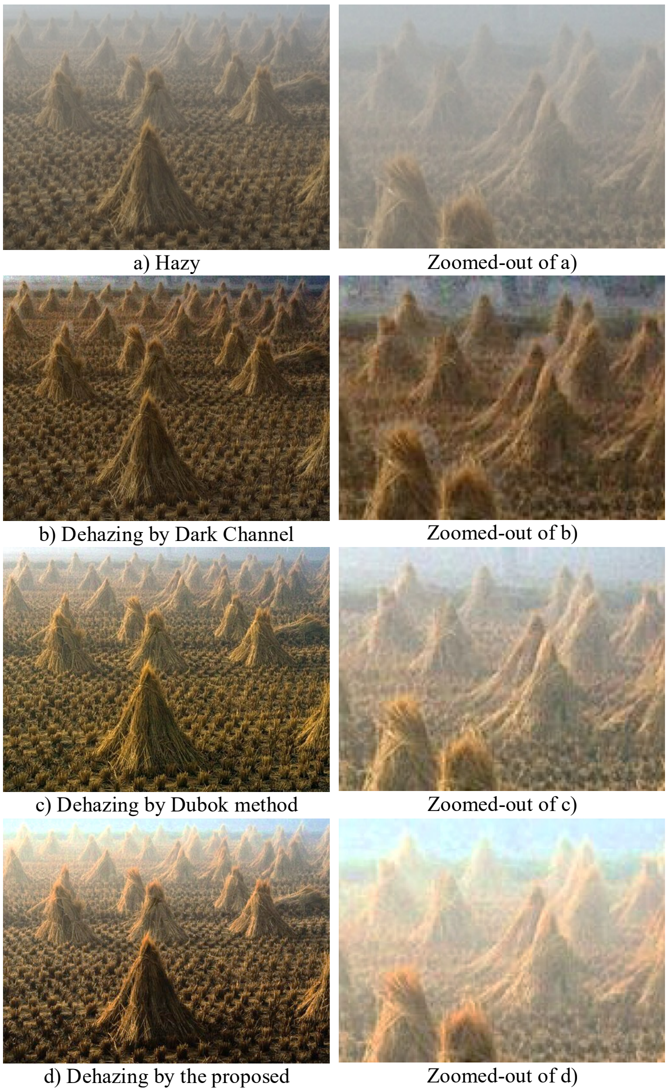

Fig. 2. Dehazing results by the methods for the cones image. NIQE score of the methods: Dark Channel is 4.3202, Dubok is 4.3557, and the proposed is **3.7302**.

B. *Synthetic Images and Test Cases*

We use hazy images of the common TAU dataset at *http://www.eng.tau.ac.il/~berman/NonLocalDehazing* for tests. All hazy images are stored in the RGB color space. We choose 12 images as in Figure 1. All images are in JPEG format with various sizes.

C. *Experimental Results and Disscusion*

We implement the DAGC method to dehaze the selected images and compare dehazing result with other methods such as the dehazing method based on the dark channel [7], the dehazing method with image entropy and information fidelity of Dubok et al. [6].

For the first test case, we dehaze for the cones image. The dehazing results are presented in Figure 2. We must notice that, the first column is the full-size image and the second column is for a cropped and zoomed-out part of the image. In the hazy image, we can see that haze density is higher for the further places. The dark channel dehazing method removed haze very well. However, for far wheat cones, some haze still remains around edges of the cones. This issue created artificial effects that made the cones look unnatural. The Dubok method and the proposed method dehazed better: although there is still a little haze on the far places of the image, avoided creating artificial effects and preserved details well. The DAGC can preserved the blue color of the sky, the green color of trees better much than the Dubok method. The NIQE score of the proposed method is the lowest (the best): Dark Channel is 4.3202, Dubok is 4.3557, and the proposed is **3.7302**.

For the second test case, we remove haze on the stadium image as in Figure 3. Haze mainly focuses on the stadium seating. The dehazing result by the dark channel method is nice, but it is slightly dark. The Dubok method and the DAGC method removed noise very well. Our proposed method removed haze slightly better than the Dubok method. The NIQE score of the DAGC is the lowest (the best): Dark Channel is 3.376, Dubok is 3.6843, and the proposed is **3.3175**.

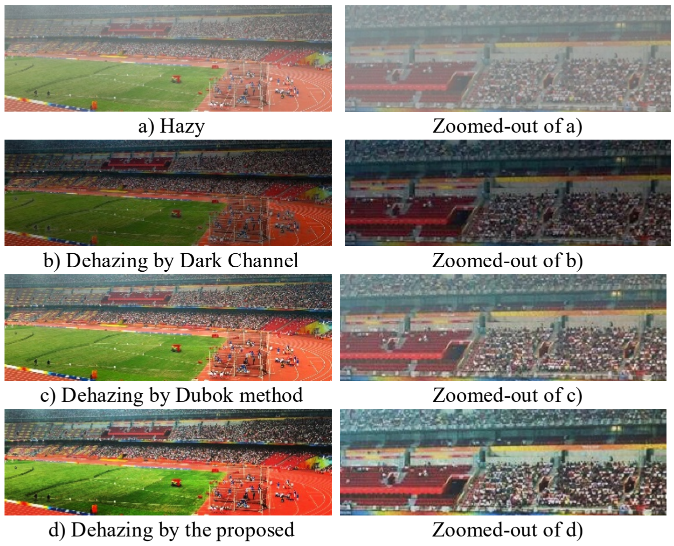

Fig. 3. Dehazing results by the methods for the stadium image. NIQE score of the methods: Dark Channel is 3.376, Dubok is 3.6843, and the proposed is **3.3175**.

The last test case is for the forest image. The dehazing results are showed in Figure 4. The dark channel method removed haze ineffectively. The result is too dark, and it also created artificial effects on tree branches. The Dubok method dehazed very well, but it made tree look greener. The proposed method removed haze effectively. We can see many details of the high-density-haze regions. The NIQE score of the proposed method is the lowest (the best): Dark Channel is 2.4261, Dubok is 2.7425, and the proposed is **2.3556**.

Fig. 4. Dehazing results by the methods for the forest image. NIQE score of the methods: Dark Channel is 2.4261, Dubok is 2.7425, and the proposed is **2.3556**.

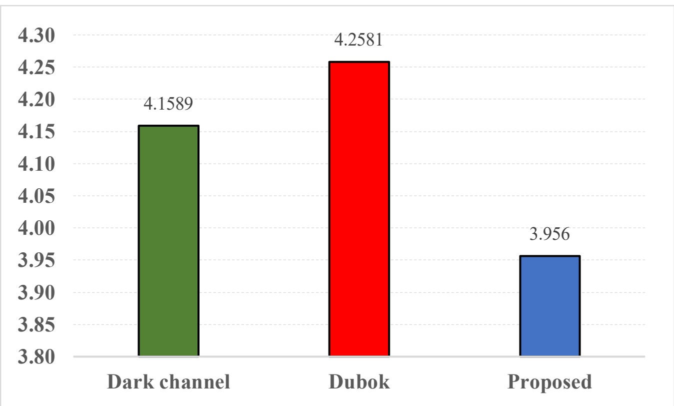

Fig. 5. The average NIQE score comparison of the methods.

Figure 5 presents the average NIQE score of dehazing results of the methods for images of the TAU dataset. As can be seen, by the average NIQE score, the DAGC dehazes the most effectively: Dark channel is 4.1589, Dubok is 4.2581 and DAGC is **3.956**.

For execution time, all methods work fast. They only take up to 2 seconds to complete the dehazing task. We must notice that, all images of the DAU dataset have various sizes (up to 1200x1200 pixels).

IV. Conclusions

In this work, a single image dehazing method based on adaptive Gamma-correction (DAGC) has been proposed. The DAGC method processes haze on the Saturation band and the Value band of the HSV color space. We increase the Saturation band by β. For the Value band, we remove haze by adaptive Gamma-correction. The adaptive parameter γ of the Gamma correction is estimated based on the weighting cumulative density function of the input image. From a variety of test cases, we can confirm that, the DAGC removed haze effectively and outperformed other compared dehazing methods.

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