Computers and Electrical Engineering 46 (2015) 371–383

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Fast single image haze removal via local atmospheric light veil estimation ☆

Wei Sun [a,*], Hao Wang [c], Changhao Sun [b], Baolong Guo [a], Wenyan Jia [c], Mingui Sun [c,d]

[a] *School of Aerospace Science and Technology, Xidian University, No. 2 Tabai Rd., Xi'an 710071, China*
[b] *School of Automation Science and Electrical Engineering, Beihang University, Beijing 100191, China*
[c] *Department of Neurosurgery, University of Pittsburgh, PA 15260, USA*
[d] *Department of Electrical & Computer Engineering, University of Pittsburgh, PA 15260, USA*

ARTICLE INFO

Article history:
Received 5 June 2014
Received in revised form 9 February 2015
Accepted 9 February 2015
Available online 5 March 2015

Keywords:
Imaging systems
Image reconstruction techniques
Illumination design
Hazy removal
Image quality assessment

ABSTRACT

In this study, a novel single-image based dehazing framework is proposed to remove haze artifacts from images through local atmospheric light estimation. We use a novel strategy based on a physical model where the extreme intensity of each RGB pixel is used to define an initial atmospheric veil (local atmospheric light veil). Across bilateral filter is applied to each veil to achieve both local smoothness and edge preservation. A transmission map and a reflection component of each RGB channel are constructed from the physical atmospheric scattering model. The proposed approach avoids adverse effects caused by the error in estimating the global atmospheric light. Experimental results on outdoor hazy images demonstrate that the proposed method produces image output with satisfactory visual quality and color fidelity. Our comparative study demonstrates a higher performance of our method over several state-of-the-art methods.

1. Introduction

Performances of outdoor vision systems for object detection, tracking and recognition are often degraded by weather conditions, such as haze, fog or smoke. Haze is the turbid medium (e.g., particles and water droplets) in the atmosphere, which can degrade the performance of the imaging system due to atmospheric absorption and scattering. The amount of scattering depends on the depth of scene and the light irradiance received by the camera attenuated along the line of sight. As a result, the haze-related degradation is varying spatially and the incoming light is scattered in the air forming an atmospheric veil in the physical atmospheric scattering model, i.e., the ambient light is reflected into the line of sight by atmospheric particles. Consequently, the degraded image loses both contrast and color fidelity. The atmospheric scattering model is illustrated in Fig. 1.

In the past decades, research on hazy removal has received great attention. Many approaches have been proposed which have advantage of restoring a single hazy image without depending on any other source of information [1–9,15–17]. In [2], Fattal used local window-based operations and graphical models for dehazing. This method achieves reasonable results in separating uncorrelated fields, but is computationally intensive. In comparison, the method proposed by Tan in [1] does not always achieve equally good results on every saturated scene. However, this method is more generic and easier to apply

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. Ferat Sahin.

* Corresponding author.
E-mail address: wsun@xidian.edu.cn (W. Sun).

http://dx.doi.org/10.1016/j.compeleceng.2015.02.009
0045-7906/

to different types of images. In particular, it works on both color and grayscale images. In [30], the method of Ancuti uses a fusion-based strategy derived from two original hazy image inputs. This method first-demonstrated the utility and effectiveness of a fusion-based technique for dehazing, but the color of the restored image is often less vivid and the contrast may not be correct. Recently, an effective image prior, called the dark channel prior [4] has been proposed to remove haze from a single image. The key observation is that most local patches in outdoor haze-free images contain some pixels whose intensity are significantly lower than other pixels in at least one of the RGB color channels. The intensity of this dark channel is considered to be a rough approximation of the thickness of the haze. The algorithm proposed by Hein [4] applies a closed-form framework of matting to refine the transmission map, and this algorithm works with color image input. Based on He's study, the dark channel prior was employed in a number of studies for single image dehazing [12,14,24,25]. For example, Tripathi and Mukhopadhyay [8] proposed an efficient algorithm using anisotropic diffusion for refining transmission map based on the dark channel prior.

In [4], based on the theory of dark channel prior and atmospheric scattering model, the global atmosphere light is defined as the brightness of an infinity scene, which is an important parameter for the image restoration based on the physical atmospheric scattering model [26]. The restored image is darker if the estimated global atmospheric light is stronger than it should be, and vice versa. In other words, halo or oversaturation effect will occur in the sky area if the estimated value is smaller than the true value [25]. Some experimental results with different global atmospheric light values are shown in Fig. 2. Similar to [4], Xiao et al. [14] chose the brightest pixels (0.2%) in the dark channel to improve the accuracy of the atmospheric light. However, some brightest pixels in white objects may lead to undesirable result of the global atmospheric light value. Yeh et al. [24] determined the range of atmospheric light empirically by selecting the top 0.1% brightest value in dark channel and the top 30% darkest value in the bright channel, then estimated the atmospheric light of the hazy image.

Despite the achievements made so far, there still lacks an effective method to accurately estimate global atmospheric light [13]. To improve the efficiency of the physical model based single image restoring algorithm [29,31], and inspired by the patch-based dark channel prior, two major factors which are critical to the quality of the restored images are addressed in details in this study. Our result provides more accurate estimation of the transmission map from which color and brightness of the image can be well restored. The major contributions of this study are outlined as follows.

(1) In order to avoid the problem caused by the error in global atmospheric light estimation, we present a strategy to define a local atmospheric light veil $A(x,y)$ from the hazy image patches with the premise that the local illumination of the scene is the same as the local atmospheric light.
(2) Both the local atmospheric light veil and the transmission map are calculated, and then the reflection component of the RGB channel is constructed from the atmospheric scattering model. This approach compensates the non-uniform illumination effects on images.

The rest of the paper is organized as follows: In Section 2, the atmospheric scattering model, some related works and typical hazy removal algorithms are discussed in detail. Section 3 presents the proposed atmospheric scattering model based on the local atmospheric light veil. Section 4 provides a detailed description of the proposed algorithms. In Section 5, comparative experiments with both subjective and objective evaluations are described. Finally, we summarize our approach and discuss its limitations in Section 6.

2. Related work and problem statement

2.1. Atmospheric scattering model

In computer vision, a widely used mathematical expression for describing the intensity L of a hazy image is established by Koschmieder [9–11]:

$$L(x,y) = L_0(x,y)e^{-kd(x,y)} + A(1 - e^{-kd(x,y)}) \quad (1)$$

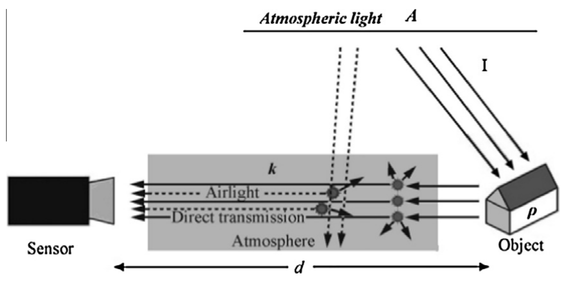

Fig. 1. Atmospheric scattering model.