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Infrared image enhancement based on atmospheric scattering model and histogram equalization

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ABSTRACT

Infrared images are fuzzy due to the special imaging technology of infrared sensor. In order to achieve contrast enhancement and gain clear edge details from a fuzzy infrared image, we propose an efficient enhancement method based on atmospheric scattering model and histogram equalization. The novel algorithm optimizes and improves the visual image haze remove method which combines the characteristics of the fuzzy infrared images. Firstly, an average filtering operation is presented to get the estimation of coarse transmission rate. Then we get the fuzzy free image through self-adaptive transmission rate calculated with the statistics information of original infrared image. Finally, to deal with low lighting problem of fuzzy free image, we propose a sectional plateau histogram equalization method which is capable of background suppression. Experimental results show that the performance and efficiency of the proposed algorithm are pleased, compared to four other algorithms in both subjective observation and objective quantitative evaluation. In addition, the proposed algorithm is competent to enhance infrared image for different applications under different circumstances.

1. Introduction

Infrared images are fuzzy and often characterized by low contrast, blurred texture details due to thermals isotropy radiation and uneven photosensitive response of infrared sensor. That is, fuzzy is the intrinsic characteristic of infrared image whether the imaging sensor is working outdoors or not. These affect the applications of infrared imaging in military, scientific, medical and other fields. Thus, it is necessary to enhance the fuzzy infrared images [1,2].

A lot of image enhancement techniques have been developed to deal with the low quality or low contrast infrared images [3–10]. Since human vision is sensitive to the light and black regions of infrared images, histogram equalization(HE) [4] and its variation, such as double plateau histogram equalization(DPHE) [5] and contrast limited adaptive histogram equalization(CLAHE) [5], are widely used. Multi-Scale algorithms based on Wavelet, Contourlet and Shearlet have been proposed to reduce noise while enhancing image details and preserving edge [7–10]. However, those methods could not well enhance fuzzy infrared images in some applications. HE together with its variation easily lead to the combination of small or similar gray values and over enhancement, resulting in the loss of details or creating visual artifacts. Multi-Scale algorithms could be useless without proper coefficients, and they are time consuming. In recent years, haze removal from a single image has been the focal point of considerable research activity. K.M. He proposed a haze removal technology [11] using dark channel prior(HRDCP), which has been regarded as one of the best haze removal algorithms during these years. HRDCP is complicated as soft matting has been used to get transmission rate and could not satisfy real time processing. Tarel proposed a fast haze removal method [12,13] using median filter, but the method is unpractical since it needs specified coefficients for each different image. Recently, researches on night video enhancement and low lighting image enhancement gain favorable enhanced results using improved dark channel prior based haze removal method [14,15]. Fuzzy infrared images are similar to visible hazy images. Inspired by the haze removal technology, we try to use atmospheric scattering model to enhance infrared images.

In order to enhance blurred texture details and improve contrast from fuzzy infrared images, we propose a contrast enhancement method based on atmospheric scattering model. We first estimate the two physical quantities in atmospheric scattering model: transmission rate which is resulting in average filtering and global atmospheric illumination. Then we gain the fuzzy free image through self-adaptive transmission rate calculated with the statistics information of original infrared image. At last, to deal with low lighting problem of fuzzy free image we propose a

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segmental plateau histogram equalization technique which is capable of background suppression. Experimental results show that the enhanced infrared image has more detail information and stronger gradient than the original, and has a satisfied perception. The objective evaluation parameters illustrate that the contrast of the fuzzy free infrared image processed by the proposed algorithm is increased effectively.

This article is organized as follows. In Section 2, atmospheric scattering model and its applicability are presented. In Section 3, we describe the algorithm of infrared image contrast enhancement based on atmospheric scattering model. In Section 4, we give experimental results and related discussions, followed by a brief conclusion.

2. Atmospheric scattering model

The optical model,which is established by Koschmieder [11,13], applied to describe of the effect of the fog is given as:

$$I(X) = J(X)e^{-\beta d(X)} + A\left(1 - e^{-\beta d(X)}\right) \tag{1}$$

where $I(X)$ represents a haze image. $J(X)$ represents a haze free image. A represents the global atmospheric light. $e^{-\beta d(X)}$ represents the transmission rate, which describes how much percent of the light emitted from the objects or scene reaches the camera, $d(X)$ represents the relative distance information of the scene and β represents the scattering coefficient of the atmosphere. In case of homogeneous atmosphere, $e^{-\beta d(X)}$ can be expressed as $t(X) = e^{-\beta d(X)}$, then we get following relationship:

$$I(X) = J(X)t(X) + A(1 - t(X)) \tag{2}$$

The first term $J(X)t(X)$ is called direct attenuation and it is an exponential decay of the intrinsic scene radiance. The second term $A(1 - t(X)$ is the addition of a white atmospheric veil, which is called airlight. $V(X)$ is used to represent the airlight [13], that is $V(X) = A(1 - t(X))$. As a consequence, Koschmieder's law can be rewritten as:

$$J(X) = \frac{I(X) - V(X)}{1 - \frac{V(X)}{A}} \tag{3}$$

The goal of haze removal model is to get $J(X)$, A and $t(X)$ from $I(X)$. In addition, the haze removal model is an ill posed problem as there exist three unknown variables and one known variable in Eq. (3). As a result, some assumptions must be propounded to solve the ill posed problem.

Infrared images are fuzzy whether the imaging sensor is working outdoors or not, and they are like the visible images degraded by fog or haze. Below Fig. 1 are two infrared images and a typical visible haze image.

They are all seemingly enveloped in a white veil though Fig. 1 (a) and (b) are essential different from Fig. 1(c). We try to use atmospheric scattering model to enhance infrared images under different circumstances.

3. Proposed method

Fig. 2 shows the steps involved in the proposed method. Each step will be introduced in the following contents.

3.1. Computing transmission rate

Transmission rate is one of the two physical quantities in atmospheric scattering model. We can get the following inequality from Eq. (2):

$$I(X) \geq A(1 - t(X)) \tag{4}$$

As the global atmospheric light A is positive and we firstly assume that A is given, then we can get:

$$t(X) \leq \left(1 - \frac{I(X)}{A}\right) \tag{5}$$

Transmission rate in HRDCP may be invalid when the statistical assumption of dark channel prior fails in the case that scene objects are inherently similar to the global atmospheric light [11]. In an effort to estimate transmission rate of infrared image effectively, our method is proposed based on the following observations:

Observation1: The changes of gray levels around the object in a homochromatic image usually happen in the areas where relative distance information of pixels differs. A big change of gray levels presents the relative distance information vary greatly, and small changes indicate similar relative distance information.

Observation2: Pixels in the neighborhood imply similar relative distance information.

To estimate the transmission rate, firstly we should calculate the relative distance information of each pixel. Then averaging filtering is adopted to reduce difference of each pixel in the neighborhood. Result of r × r average filtering of each pixel presents the relative distance information for each pixel. The operation of $r \times r$ averaging filtering can be expressed as:

$$I_{aver}(X) = average_{r\times r}(I(X)) \tag{6}$$

where I_{aver} is the result of averaging filtering, the radius of average filtering mask r is set to 3.

I_{aver} replaces the relative distance information, transmission rate can be rewritten as $t(X) = e^{-\beta \bullet I_{aver}(X)}$. Eq. (5) enlightens a potential linear relationship between $t(X)$ and I_{aver}. Then the

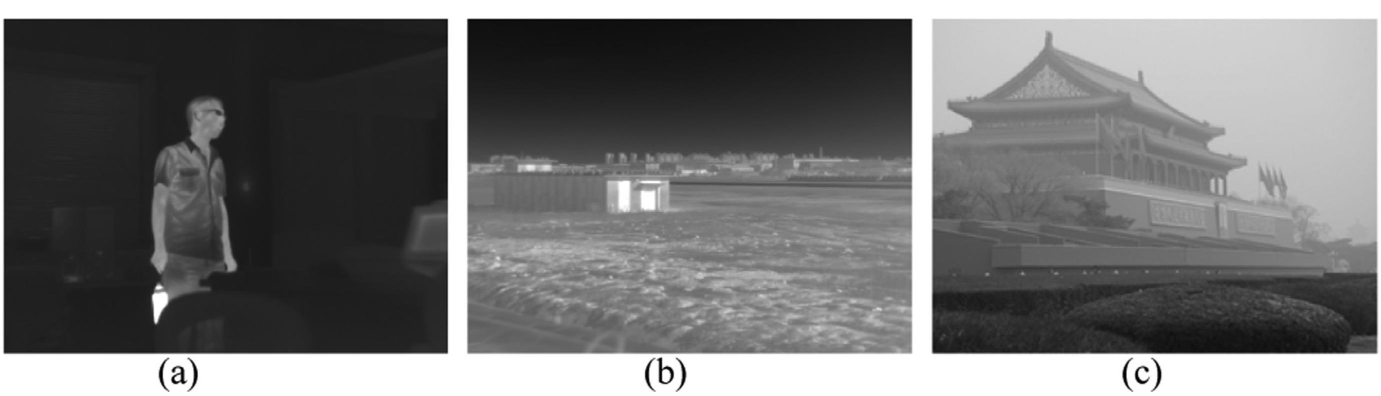

Fig. 1. Different images: (a) indoor infrared image, (b) outdoor infrared image, (c) visible haze image.