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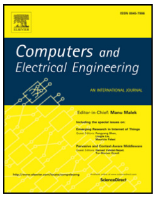

Piecewise linear model for haze level estimation and an efficient image restoration technique☆

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ABSTRACT

In this paper, a piecewise linear predication model that relates light extinction coefficient (b_{ext}) to *log* of image contrast/transmission is proposed. The objective is to calculate more accurate b_{ext} values compared with previous treatments which used linear model of contrast relationship only. A multivariate linear regression model is learned for each linear portion of the model. Results show superior behavior of the proposed model in terms of error calculated between estimated values and ground truth values. Moreover, an effective approach to dehaze and enhance outdoor images captured under adverse weather conditions is introduced. A raw transmission map is estimated using a dark channel prior, then guided image filtering is used in two stages; first for transmission map refinement, second for details enhancement. Guided filtering not only exhibits the edge-preserving smoothing, but also a structure transferring property. Details enhancement results in improved visibility with minimum information loss.

1. Introduction

Haze is a common natural phenomenon caused by atmospheric absorption and scattering, due to the presence of suspended particles in the atmosphere [1,2]. Haze reduces the contrast of the scene and diminishes its visibility. Quantitative estimation of atmospheric visibility is importantly required, especially with growing indication of the air pollution. Traditional means of measuring air pollution using specialized equipments is very expensive, while digital images can be used to provide the same task with high accuracy and lower cost. Dehazing is essential in many image processing and computer vision applications such as navigation, object tracking and recognition [3,4]. Enhancing image details and edges leads to significant improvement in its visual appearance. Image sharpness is useful in image post-processing applications such as segmentation and detection. Measuring image quality can be accomplished through subjective evaluation. In practice, depending on human observers is time-consuming and expensive. Moreover, subjective evaluations cannot be incorporated into automatic systems. Objective image quality measures can automatically evaluate image quality in a way that strongly correlates to human judgment. Quality assessment (QA) algorithms interpret quality as fidelity or similarity with a reference or perfect image [5,6].

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In this paper, an effective piecewise linear predication model that relates light extinction coefficient (b_{ext}) to log of image contrast/transmission to calculate more accurate b_{ext} values is proposed. Also an efficient approach to dehaze and enhance outdoor images with minimum information loss is introduced. Guided filtering is employed in a cascaded manner; for haze removal in the first stage, and for details enhancement in the second. Guided filtering is compared with adaptive manifolds high-dimensional filtering previously introduced in [7] for image enhancement. Effective quality assessment methods are used for objective evaluation.

The rest of the paper is organized as follows: Section 2 presents in details the proposed approach of b_{ext} estimation. The proposed image dehazing and enhancement techniques are detailed in Section 3. Conclusions are provided in Section 4.

2. Proposed approach for visibility estimation

Since our objective is to use digital images to calculate more accurate values of b_{ext}, a two steps algorithm is proposed:

1. Based on certain threshold (point between 2 consecutive linear pieces), decide (qualitatively) the haze category (low, medium, and high), which corresponds to a linear portion of the b_{ext} to natural logarithm of contrast/transmission relation.
2. For each category which corresponds to a linear piece of the relation, apply the linear model associated with it.

Training set is chosen from images having b_{ext} to natural logarithm of contrast/transmission curve with a suitable step increment of b_{ext} values such that most of the points lie on a fitting line of this part of the curve, or pass near it as much as possible. In the following subsections the underlying elements of this approach are explained.

2.1. Light extinction coefficient relation to image contrast/atmospheric transmission

Gases and particles scatter and absorb radiation, and thus cause visibility degradation. Light extinction coefficient b_{ext} which is the sum of light scattering b_{scat} and light absorption b_{abs} coefficients, measures the total loss of beam intensity. The magnitude of difference in image intensity over a short spatial distance is defined as the local contrast [8]:

$$C = |\nabla I| \tag{1}$$

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

where J is the scene radiance, A is the atmospheric light and t is the atmospheric transmission.The contrast is computed as the average of the gradient magnitude over a region Ω:

$$C = \frac{1}{|\Omega|}\sum_{\Omega}|\nabla I| \tag{3}$$

The light extinction coefficient is given by:

$$b_{ext} = \frac{\ln C}{r} - \frac{\ln|\nabla J|}{r} \tag{4}$$

where $\frac{1}{r}$ is the scaling factor and $\frac{\ln|\nabla J|}{r}$ is the offset. Transmission can be estimated based on dark channel prior, and b_{ext} can be calculated as:

$$b_{ext} = \frac{\ln t}{r(x)} \tag{5}$$

Pure scaling results in poor performance, so an offset should be included to accommodate for errors in the model.

2.2. Proposed model

Graves and Newsam [8] modeled the log of image contrast/transmission to b_{ext} relation as a linear model with a function having the following form:

$$f(x) = \alpha_1.x + \alpha_0 \tag{6}$$

where x is the log of image contrast/transmission, α_1 is the scaling factor and α_0 is the offset. In [9], they showed that using measured contrast from several regions of the image yields more accurate b_{ext} results. Since multiple image regions are incorporated, multivariate linear regression is used. Using 24 image regions, we have 24 instances of Eq. (6). Assuming a constant value for the b_{ext} of the scene, these instances can be summed to get:

$$nb_{ext} = \sum_{j=1}^{n}\frac{\ln C_j}{r_j} - \frac{\ln\left|\nabla J_j\right|}{r_j} \tag{7}$$

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