Visibility restoration of single hazy remote sensing images

Tamilarasi.M[1], Ameena Bibi.N[2]

PG Scholar[1], Assistant Professor[2]
Department of ECE, Government College of Technology
Coimbatore, India

Abstract— **Remote sensing Images are widely used in various fields including agricultural, forestry, hydrology and military. However, remote sensing Images are easily degraded by atmospheric scattering due to suspended particles in the atmosphere such as haze, fog, mist. Most of haze removal methods based on single image have ignored the effects of sensor blur and noise. To overcome this issue, a simple but effective image dark channel prior technique with deformed hazing imaging model has been proposed. The atmospheric light and transmission are estimated according to the new model combined with dark channel prior. Transmission estimated can result in discontinuity. After that scene radiance is recovered.In order to eliminate halo artifacts still present in the scene radiance, various filters are used. . The proposed dehaze algorithm has been simulated using MATLAB R2013a. The Performance metrics and visual analysis shows that the proposed approach gives better performance compared to existing methods with low processing time and retains very fine details.**

Keywords—*sensor blur and noise, dark channel prior,Haze removal, remote sensing*

I. INTRODUCTION

Remote sensing images have been widely used in various fields . Widespread use of remote sensing images is predicated on high-quality images. However, remote sensing is usually vulnerable to weather effects. In general, remote sensing images are taken at a considerable distance from the earth's surface. During propagation, the incoming energy interacts with the atmosphere. Some atmospheric effects, such as haze, fog, smoke and cloud, degrade the quality of the received images. Therefore, an effective haze removal method is of great significance for improving the visibility of remote sensing images. However, single image dehazing is a challenging problem because only a hazy image is given.

For the single outdoor image, haze removal algorithms can be classified into three main categories: 1) algorithms based on priors or assumptions. Fattal et al. [2] increased scene visibility and recovered haze-free scene under the assumption that the transmission and the surface shading are locally statistically uncorrelated. He et al. [3] proposed the dark channel prior based on a kind of statistics of haze-free images to remove haze from outdoor images. This kind of methods removes haze through estimating parameters of the haze imaging model, which can achieve satisfactory results; 2) image enhancement based on image processing, such as histogram equalization [4], retinex [5]. Since these methods mainly focus on image enhancement and consider little of the imaging model of degraded images, unsatisfactory results will be obtained when the scene is complex; 3) dehazing based on a fusion strategy. Ancuti et al. [6], [7] are the first to introduce a fusion technique to single image dehazing. In their method, two inputs derived from the original image are weighted by three normalized weight maps (luminance, chromatic and saliency) and blended in a multi-scale fusion finally to eliminate haze effects.

For remote sensing images, a number of image-based algorithms are proposed to dehaze. Zhang et al. [8] developed a haze optimized transformation (HOT) algorithm, derived from the analysis of a visible-band space, to remove the haze region from images captured by Landsat. Du et al. [9] used wavelet analysis to detect and remove haze from high-resolution satellite images. Shen et al. [10] proposed an adaptive homomorphic filter to eliminate thin cloud effects from visible remote sensing images while retaining the cloudless region. The fusion-based technique is also applied to dehaze from remote sensing images [11]. With the development of dark channel prior [3], some other researchers introduced the prior and haze imaging model to remote sensing images' dehazing. Long et al. [12] utilized the dark channel prior and a low-pass Gaussian filter to estimate parameters of the haze imaging model to remove the haze. Among above dehazing methods, the dark channel prior combined with the haze imaging model has proved to be simple and effective. There is an increasing number of dehazing algorithms based on this work in recent years [13]–[16]. However, the dark channel prior has been developed originally according to the statistics of outdoor haze-free images which are very different from remote sensing images because of the different imaging distance. Therefore, it often causes color drift phenomenon when applied to remote sensing images directly. In this letter, an improved estimation algorithm based on a deformed haze imaging model and the dark channel prior is proposed, which can successfully remove the haze from remote sensing images without color drift.

II. REMOTE SENSING IMAGE DEHAZING

Haze removal is performed on the basis of dark channel prior with deformed haze imaging model is proposed. Most of haze removal methods have not considered the effect of sensor blur and noise. Dehazing considered along with the effect of sensor blur and noise is effectively removed by means of non local mean filtering and canny edge detection is used to enhance the sharpness of image. Then the dark channel prior assumption along with deformation is used to remove haziness from remote sensing images. In order to eliminate halo artifacts still present in the scene radiance, various filters are used

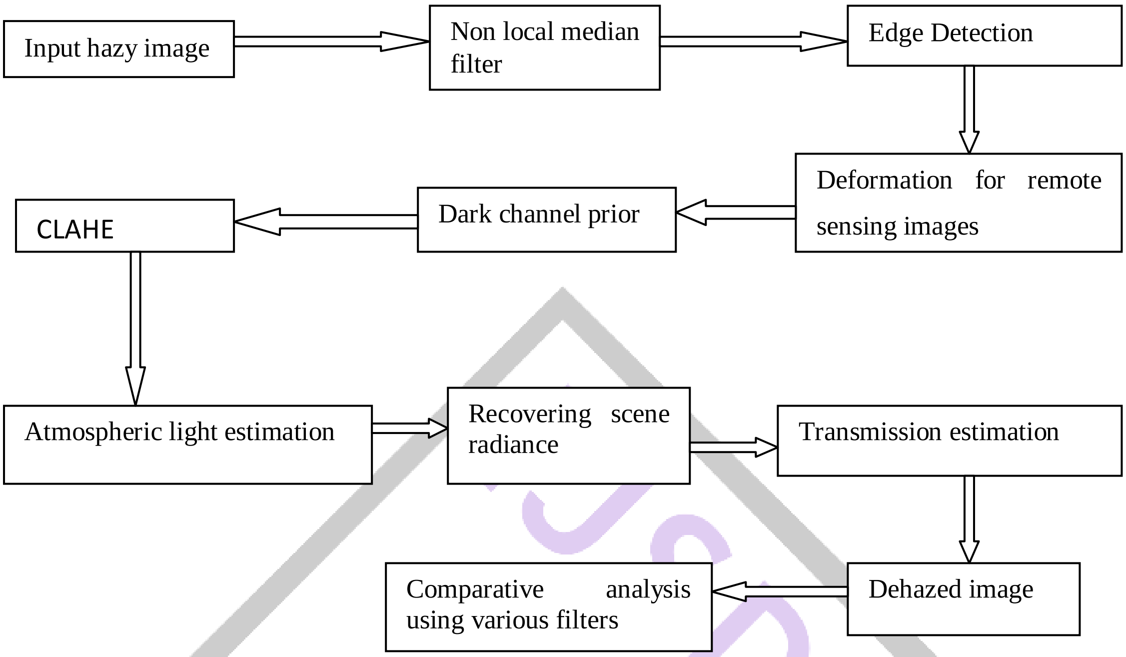

Fig.1 block diagram for Dehazing algorithm is shown in below

DEFORMING THE HAZE IMAGING MODEL

The dark channel prior proposed by He et al. [3] is used to estimate the atmospheric light A and the transmission t from an input image. The prior is based on the following observation on outdoor haze-free images: In most of the nonsky patches, at least one color channel has some pixels whose intensities are very low and close to zero [3]. Equivalently, the minimum intensity in such a patch is close to zero. Obviously, the average intensity of remote sensing images' dark channel is low, but not close to zero. The difference in dark channels between remote sensing images and outdoor images is significant and cannot be neglected. the intensity histogram of remote sensing images dark channels has a rightward translation relative to that of outdoor images. To make the dark channel prior suitable for remote sensing images, the histogram of dark channels of remote sensing images is expected to move to left by C, which means J needs to be subtracted by C. For this purpose, we subtract a term Ct(x) from both sides of the haze imaging model.

$$I(x) - Ct(x) = J(x)t(x) + A(1 - t(x)) - Ct(x) \quad (1)$$

Further simplifying:

$$I(x) - Ct(x) = (J(x) - C)t(x) + A(1 - t(x)) \quad (2)$$

where C(C > 0) is derived from a kind of statistics of haze-free remote sensing images and is used to reduce the deviation when using the dark channel prior to estimate the transmission.

ESTIMATING THE ATMOSPHERIC LIGHT

The method used to calculate A is as follows.

1) We calculate the dark image J_{dark} based on (1).
2) Then we extract the top 0.1 % of the brightest points.
3) Finally, we choose the points with the maximum average brightness from the extracted points as A.

ESTIMATION OF TRANSMISSION

we define the dark channel of an arbitrary remote sensing image J with leftward translation C as:

$$(J(x) - C)^{dark} = min_{y\in\Omega(x)(}(\min_c max(J^c(y) - C.0)^c)) \quad (3)$$

where $(J(x)\text{-}C)^c$ is a color channel of J(x)-C and (x) is a local patch centered at x and meanwhile ,the max operator is used to avoid negative values caused by J(x)-C.

We assume that the atmospheric light is given, and the transmission in a local path (x) is constant, denoted as $\hat{t}(x)$. Then calculating the dark channel on both sides:

$$\min_{y\epsilon\Omega(x)}(\min_c I^c(y)) - Ct(x) = min_{y\in\Omega(x)}(\min_c max(J(y) - C.0)^c)) + A_0(1 - t(x)) \quad (4)$$

The intensity of dark channel for J(x) -C is low and tends to be zero according to the dark channel prior:

$$min_{y\in\Omega(x)}(\min_c(max(J^c(y) - C.0)^c)) = 0 \quad (5)$$

will lead to:

$$\min_{y\in\Omega(x)} \min_c I^c(y) - Ct(x) = A_0(1 - t(x)) \quad (6)$$

The transmission $\hat{t}(x)$ can be estimated as follows:

$$t(x) = \frac{A_0 - \min_{y\in\Omega(x)} \min_c I^c(y)}{A_0 - C} \quad (7)$$

which is our estimation formula for transmission based on deformed haze imaging model and dark channel prior.

RECOVERING SCENE RADIANCE

The scene radiance J(x) can be restored by

$$J(x) = A_\infty \times \frac{I(x)/A_\infty - kV(x)}{\max(t(x), t0)} \quad (8)$$

The transmission roughly estimated can result in discontinuity of t even though no abrupt depth discontinuities occur. Main problem are some halo and block artifacts still present in the recovered haze free image. Then the recovered haze free image is filtered through Gaussian, Median, Bilateral filter and its performance is compared.

BILATERAL FILTERING

Bilateral filter smooth the image along with preserving its edges. It is simple and non iterative. By the bilateral filter, gray levels are combined based on properties such as the photometric similarity and geometric closeness, the preference is made based on the values closer compared to distant values in both range and domain.

GAUSSIAN FILTER:

Gaussian smoothing is very effective for removing Gaussian noise. They are linear low pass filters. The weights are computed according to a Gaussian function where the weights give higher significance to pixels near the edges so that it reduces edge blurring. This filter is rotationally symmetric and computationally efficient.

MEDIAN FILTER:

The mean filter is a simple method of denoising images by reducing the amount of intensity variation between one pixel and the next. The basic idea is to replace each pixel value in an image with the mean value of its neighbours pixel together with itself thus removing the unwanted pixel which is considered as noise. It is the optimal linear filter for the Gaussian noise. The main drawback is this filter blurs the edges, remove the lines and other image details belong to that class of filters which are used as edge preserving smoothing filters which are non-linear filters. It also has some disadvantages. The median fi lter removes both the noise and the fine detail since it can't tell the difference between the two

III SIMULATION RESULTS

To implement the dehazing algorithm is simulated using MATLAB R2013a. The haze density, root mean square error, power to signal noise ratio, structural similarity index metric and Edge preservation index were analyzed for various images. From the analysis, it is observed that the Gaussian filter produce visually appealing dehazing images with low processing time and retains very fine details.

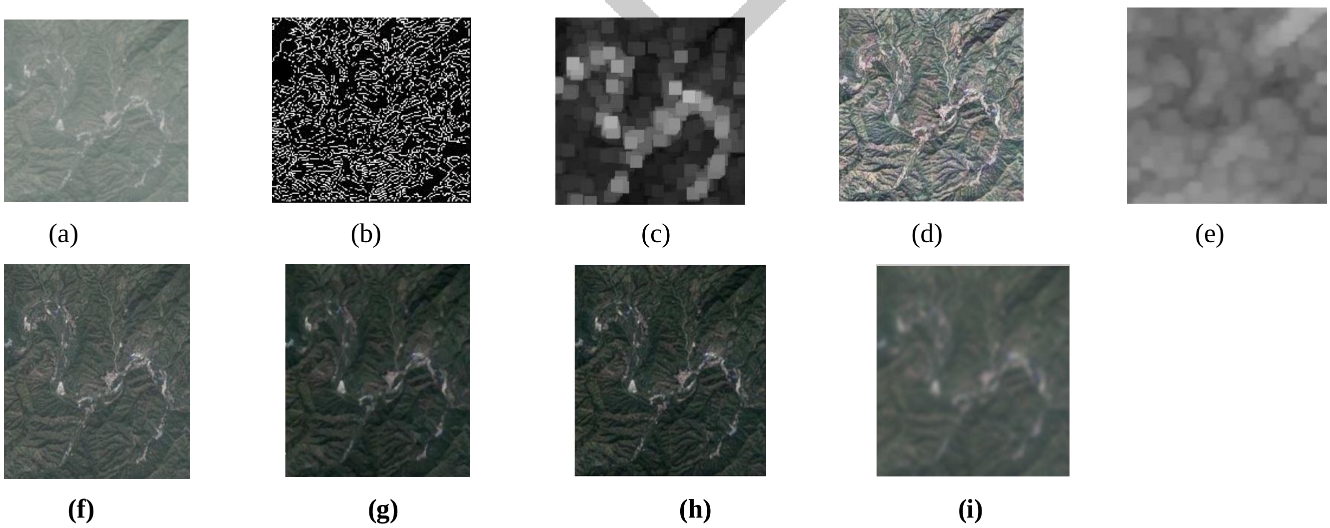

Fig.2. *Experimentel results of dehazing algorithm. (a) hazy image (original size is 256 × 256);(b) canny edge detection;(c)dark channel prior (d)CLAHE(e)Transmission map(f)dehazed image(g)Gaussian filtered image;(h)median filtered image (i)bilateral filtered image.*

A. *Performance Measurement*

The efficiency of proposed filter can be qualitatively verified by doing performance evaluation. The dehazed image can be qualitatively evaluated using numerical evaluation metrics like Mean Square Error, Root Mean Square Error, Peak Signal To Noise Ratio, Correlation Coefficient, Structural Similarity Index, Edge Preservation Index, E-Metric And R-Metric.

MSE and RMSE denotes the amount of error present, PSNR valued quantifies the amount of information retained after dehazing, SSIM and correlation coefficient measures the similarity between two images, whereas EPI, e-metric, r-metric denotes the total amount of visible edges in the restored image. SSIM and correlation coefficient is considered as an important factor.

PERFORMANCE ANALYSIS FOR IMAGE

Haze density of input hazy image = 133.850

Parameters	**Performance after scene recovery by Bilateral filter**	**Performance after scene recovery by Gaussian Filter**	**Performance after scene recovery by median filter**
Haze density	50.3025	49.3949	50.0145
MSE	0.5187	0.5177	0.5177
Correlation coefficient	0.9267	0.9925	0.8631
EPI	1.0024	1.1671	1.086
SSIM	0.9662	0.9692	0.9611
RMSE	0.7207	0.7195	0.7195
E-Metric	0.6427	0.6275	0.6427
R-Metric	0.0689	0.02674	0.01542
PSNR	50.9897	50.9815	50.9899

From the analysis, it is observed that the dehazing were efficiently performed using Gaussian filter. Because of the EPI,SSIM, correlation coefficient should be high and Haze density should be low compared with other filters.

IV. CONCULSION AND FUTURE WORK

In this paper, comparative analysis of various filters such as Median, Gaussian, Bilateral and Performance Metric such as Peak signal to noise ratio, Structural similarity index, edge preservation index, correlation co efficient, e-metric and r-metric have been carried out. From this comparative analysis, Gaussian filter produce visually appealing dehazing images with low processing time and retains very fine details. Compared with the other two state-of-the-art methods, our method has the following four advantages: 1) color consistency can be achieved; 2) the transmission is insensitive to the scene texture; 3) it can be used to remove non-uniform haze to a certain extent and 4) it is applicable to general haze removal through adjusting C with the statistics of haze-free images dark channels.

Further work aims to develop the procedure for hazy videos and to implement this approach in dsp processor.

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