Fast Single Image Dehazing using Recursive Guided Filter

Jitendra Mishra[1], Sanket Choudhary[2]

[1]M-Tech Research Scholar, [2]Research Guide

Department of Electronics and Communication Engineering, LNCTS, Bhopal

Abstract - Fog is a natural atmospheric phenomenon that visually degrades urban scenery and is hazardous to human visibility and the transportation. Due to the suspended particles (such as fog, haze, rain and snow) in the atmosphere the visibility is severely degraded which is hazardous as significant number of accidents and delays in the transportation sector occur due to limited visibility. In this paper, we propose a new dehazing method for single digital image based on depth of the fog estimation by recursive guided filter and dark channel prior methods. In the proposed method, an accurate depth of the fog is essential for recovering the scene without the visual effects degradation due to defogging incorporating temporal knowledge.

Keywords: fog, haze, dark channel prior, Recursive Guided Filter

I. INTRODUCTION

Images of outdoor scenes are often subjected to atmospheric degradation, such as haze and fog, caused by particles that absorb and scatter light as it travels to the observer. With diverse weather situations (such as haze, fog, smoke, rain, or snow) will cause versatile visual effects in images or videos in both spatial and/or temporal domains. Images of outdoor scenes are usually degraded by the turbid medium (e.g., particles, water-droplets) in the atmosphere. There have several mishaps due to the reduced visibility caused by diverse weather situations. Often the suspended atmospheric particle (such as fog, haze, rain and snow) which degrades the visual capability of the individuals results in hazardous accidents and delays in the transportation sector.

Fog is one of the common complex atmospheric phenomenon wherein a visible mass consisting of cloud water droplets or ice crystals suspended in the air at or near the Earth's surface and obscure the scenes [1]. The foggy conditions generally depreciates the performances of outdoor vision systems and reduces the visibility of the scenes and lowers the reliability of outdoor surveillance systems; it reduces the clarity of the satellite images; it also changes the colors and decreases the contrast of daily photos, which is an annoying problem that need to addressed [1].

Diverse climate conditions such as fog, mist and haze drastically reduce the atmospheric visibility. Poor atmospheric visibility degrades perceptual image quality and performance of the computer vision algorithms such as surveillance, tracking and navigation. The basic questions that needed to be addressed are as follow

- How diverse weather conditions affects the visual appearance of scenes
- How to calculate the concentration of fog in the digital image
- How to find the relationship between the affect the pixel values and the visual degrading factors

II. PREVIOUS WORK

In this section, we describe the theoretical foundation of the proposed research. Commonly existing defogging can be done by two ways i.e., multiple images fog removal method and single image fog removal method. Chen, Mengyang et al. (2009) [4] has illustrated that in adverse weather such as fog and haze, the visibility of scene can significantly be degraded. They employed global and local rectifications as a base for the iterative algorithm to adjust the color distortion. The proposed technique works by treating the inherently similar pixels (i.e. background) of some object and atmospheric light differently of like image matting and iterative matte optimization. This technique models the image as a linear combination of foreground image and background image by a variation map.

Xu, et al. (2009) [7] has examined that images degraded by fog suffer from poor contrast. In order to remove this effect a contrast limited adaptive histogram equalization (CLAHE)-based method was proposed. To clip the histogram this method establishes a maximum value and redistributes the clipped pixels equally to each gray level. This algorithm is performed in three steps; firstly the color images captured by camera in foggy is converted from RGB (Red, Green and blue) color space to HSI space. The reason behind the conversion is the HSI (Hue, Saturation and Intensity) represents colors similarly how the human eye sense color. The HSI color represent attractive color model for image processing applications. Second, the intensity component of the image is processed by CLAHE.

The hue and intensity remain unchanged. A new HSI image is obtained. Finally the new image in HSI color space is converted back to RGB color space to get the original image without degradations.

Wang, et al. (2010) [7] has explored that haze removal from the image depend upon the unknown depth information. This algorithm is based on the atmospheric scattering physics-based model. In this on selected region a dark channel prior is applied to obtain a novel estimation of atmospheric light. This model is based upon some observation on haze free outdoor image. The intensity of dark channel calculated gives rough approximation of the thickness of haze. Yu, et al. (2011) [8] has proposed a novel fast defogging method from a single image based on the scattering model. A white balancing is used prior to the scattering model applied for visibility restoration. Then an edge-preserving smoothing approach based on weighted least squares (WLS) optimization framework to smooth the edges of image. Shuai, et al. (2012) [9] discussed problems regarding the dark channel prior of color distortion problem for some light white bright area in image. An algorithm to estimate the media function in the use of median filtering based on the dark channel was proposed. After making media function more accurate a wiener filtering is applied. By this fog restoration problem is converted into an optimization problem and by minimizing mean square error a clearer, finally fog free image is obtained.

Cheng, et al. (2012) [10] has proposed a lowest channel prior for image fog removal. This algorithm is simplified from of dark channel prior. It is based on a key fact that fog-free intensity in a color image is usually a least value of tri-chromatic channels. In dark channel prior to estimate the transmission model it performs as a minimum filter for lowest intensity. This filter leads to halo artifacts, specifically in the neighborhood of edge pixels. In this algorithm instead of minimum filter they utilizes exact O(1) bilateral filter based on the raised cosines function to the weight value of neighbor to get fog-free image. Xu, et al. (2012) [11] has recommended a model based on the physical process of imaging in foggy weather. In this model a fast haze removal algorithm which is based on a fast bilateral filtering with dark channel prior is explained. Firstly, the atmospheric scattering model is used to describe the formation of haze image. Then an estimated transmission map is formed using dark channel prior. Then it is combined with gray scale to extract the refined transmission map by using fast bilateral filter instead of soft matting. The reason why the image is dim after the use of dark channel prior is observed and a transmission map formula is proposed to restore the color and contrast of the image. Kang, et al. (2012) [12] has proposed a single image based rain removal frame work by properly formulating rain removal as an image decomposition problem based on MCA (morphological component analysis). Before applying a proposed method image is decomposed into low and high-frequency parts using a bilateral filter. By using sparse coding and dictionary learning algorithms the high frequency part is decomposed into rain component and non-rain component. Sparse coding is a technique of finding a sparse representation for a signal with a small number of nonzero or significant coefficients corresponding to the atoms in a dictionary. After this pre-processing step the proposed MCA (morphological component analysis)-based image decomposition to the HF part that can be further decomposed into the rain component. Tripathi, et al. (2012) [13] has studied that fog formation is due to air-light and attenuation. Air-light increases the whiteness and attenuation increases the contrast in the scene. So a method is proposed which use bilateral filter to recover scene contrast and for the estimation of light. In this algorithm both pre and post processing steps are performed. Histogram equalization is used as pre processing to increase the contrast of the image prior to fog removal and also help to get better estimation of air-light map. Histogram stretching is used as post processing for increasing the contrast of fog removed image. Tripathi, et al. (2012) [14] has proposed an algorithm which use anisotropic diffusion for estimation of air-light. For color image RGB (red, green and blue) and HSI (Hue, saturation and intensity) models are used.

Wei, et al. (2013) [15] has proposed a fast single image de-hazing algorithm based on the atmospheric scattering model. The proposed algorithm use numerical correction for the phenomenon. Firstly a dark channel phenomenon is applied via optical method, and approach for solving the parameter in atmospheric scattering is derived. Secondly a gray-scale opening operation and fast joint bilateral techniques, to calculate the global atmospheric light is used. Finally, to calculate the scene albedo (reflection coefficient) the model is inverted. Im, et al. (2013) [16] has proposed a novel contrast enhancement method for backlit images that consists of three steps: i)computation of the transmission coefficients using the dark channel prior ii) generation of multiple images having different exposures based on the transmission coefficients and iii) image fusion. This approach first extracts under-exposed regions using the dark channel prior map, and then performs spatially adaptive contrast enhancement. Kil, et al. (2013) [17] has recommended a de-hazing algorithm based on dark channel prior and contrast enhancement methods. They combined the advantages of these two conventional approaches for keeping the color while de-hazing process. An optimization function is proposed to balance between the contrast and colors distortion, where the contrast measure follows the conventional image statistics and the hue component is used to constrain the color changes. Noh, et al. (2013) [18] has proposed a de-hazing method for single image on super-pixel domain. They applied Dark Channel Prior to the super pixel, instead on the conventional fixed size patch, to estimate the transmission map. They exploited quick shift algorithm to estimate the transmission map.

III. PROPOSED ALGORITHM

Our algorithm for haze detection and reduction is based on dark channel prior technique. As dark channel technique is based on signal image of haze condition, it is more popular than other technique.

For dehazing, a mathematical equation is used to define formation model of haze image is shown in equation (1).

$$I(x) = J(x) * t(x) + A * (1 - t(x)) \qquad (1)$$

where $I(x)$ is our haze image, $J(x)$ is real scene radiance image and x define the position of pixel. A is atmospheric light value and t is transmission coefficient matrix.

Haze is slow vary quantity in outdoor images. Its depth is determine by transmission coefficient matrix. In sky region, value of transmission coefficient matrix is near to zero, and in other region its value vary from zero to one.

We have only single item from equation(1), that is haze image I(x), reset of the item (J(x), A, t) are unknown. So to find other items some assumption be taken, that local patches in haze free image have very low value of intensity at least one of the color channel, except the sky region. So by taking this assumption, the dark channel of real scene radiance image or haze free image is define by equation (2).

$$J^{dark}(x,y) = \min_{c\in\{R,G,B\}}\Big(\min_{(x,y)\in\Omega(x,y)}(J^{c}(x,y)) \approx 0 \qquad (2)$$

where Ω(x) is local patches located at center of x.

figure(1) define our algorithm for improving dehazing technique of dark channel prior based on enhancing edge of haze images using adaptive manifold filter which improve dark channel image.

A. DCP Image

Dark channel image is estimated by applying equation equation(4) on haze image fig 2.

$$I^{dark}(x,y) = \min_{c\in\{R,G,B\}}\Big(\min_{(x,y)\in\Omega(x,y)}(I^{c}(x,y)) \qquad (3)$$

This method search minimum value of intensity in local patches and generate a dcp image as shown in figure 4(a)

B. Fine DCP Image

Haze free image estimated by different method for dehazing suffer from halo effect as shown in fig 3. Halo effect reduce the edge information from haze image. Fining DCP image, with respect to minimum channel image generated from haze image, reduce halo effect.

$$FineDCP = \max_{c\in\Omega(x)}\Big(\min_{(x,y)\in\Omega(x,y)}(I, DCP)\Big)$$

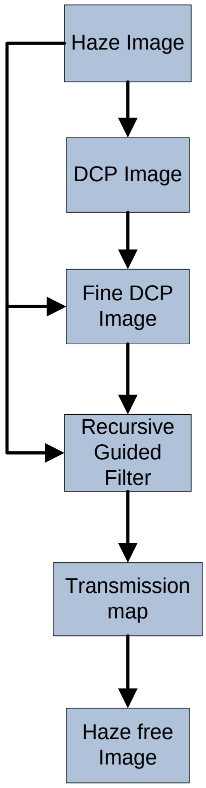

Figure 1. basic flow chart for our algorithm

C. Recursive Guided Filter

Halo Effect not completely remove by Fining DCP image(shown at figure 4(b)). To remove effect of halo, a recursive Guided Filter used to fine more DCP image, which result complete remove halo effect. Final fine DCP shown as figure 5.

figure 2. Haze image

D. Atmospheric Light Value Estimation

Atmospheric light value estimation from top 0.1% brightest pixel value from fine dark image (shown in fig 4(b)) . The average value of 0.1% of brightest pixel represent atmospheric light value. In haze image, brightest pixel mainly present in sky region. If any object have brightest value, like white car, affect the atmospheric value.

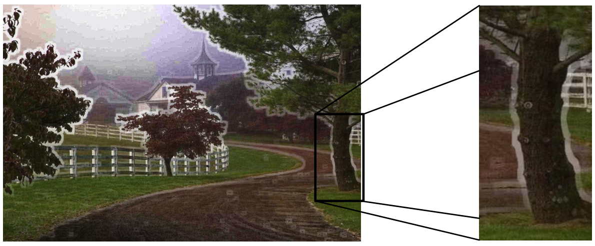

figure 3. halo effect

(a) (b)

figure 4, (a) dark channel prior image, (b) fine dark channel prior

figure 5. final fine DCP image

E. Transmission Coefficient Matrix

We have find atmospheric light value and dark image of haze image. to estimated transmission matrix, we assume that value of transmission matrix not very in local small patches, so apply local patches in equation (1) we get

$$\min_{\Omega(x,y)}(I^{c}(x,y)) = t(x,y) * \min_{\Omega(x,y)}(J^{c}(x,y)) + A_{c}(1-t(x,y)) \quad (4)$$

from equation(2) , above equation become

$$\min_{\Omega(x,y)}(I^{c}(x,y)) = A_{c}(1-t(x,y)) \quad (5)$$

then , rearrange equation (5) to estimates transmission matrix simply by:

$$t(x) = 1 - \frac{\min\limits_{c\in\{R,G,B\}}(\min\limits_{(x,y)\in\Omega(x,y)} I^{C}(x,y))}{A^{C}} \quad (6)$$

above equation(6), gives as estimated transmission matrix. As dark channel prior is not good method for sky region. As the transmission matrix value approaches to zeros then,

$$\min_{c\in\{R,G,B\}}(\min_{(x,y)\in\Omega(x,y)}(I^{c}(x,y)) \rightarrow 1 \quad (7)$$

This make dehaze image look unnatural mainly at sky region, as value of sky region is almost equal to atmospheric value.

To make dehaze image look natural, a parameter ω in equation (6) ,

$$t(x) = 1 - \omega * \frac{\min\limits_{c\in\{R,G,B\}}(\min\limits_{(x,y)\in\Omega(x,y)} I^{C}(x,y))}{A^{C}} \quad (8)$$

where the value of ω varies from 0 to 1, ω value depend on application.

Final transmission map image show in below

figure 6, transmission map image

figure 7 Dehaze image

F. Recovering Scene Radiance

As we have find all required parameter from dark channel image used to remove haze from images, that are atmospheric light value and transmission matrix. for recovering real scene equation (1) is rearrange as given below:

$$J(x) = \frac{I(x) - A}{t(x)} - A \qquad (9)$$

In equation (9), transmission matrix $t(x)$ may have zero value coefficient, which make radiance image prone to noise. This occur maximum in sky region. To remove noise effect, make limit to transmission matrix coefficient up to value t_0. So equation (9) write as

$$J(x) = \frac{I(x) - A}{\max(t(x), t_0)} - A \qquad (10)$$

The final real scene radiance image show in figure 7:

figure 8, 1st coloum is input image, 2nd coloum is DCP image, 3rd coloum is fine DCP with recursive guided filter, 4th transmission map and last coloum output image

IV. EXPERIMENTAL RESULTS

Proposed algorithm develop in MATLAB R2015a on Personal computer with 3.1 GHz speed. Proposed algorithm apply on several images out of which some result shown in this paper (shown on figure 8). On comparing our algorithm

with other algorithm of Tarel[6] and He[5] , gives better result both in image restoration and time complexity. As He[] use soft matting algorithm for dehazing an image, time taken to dehaze image is more than 5 minute for image size 1200x800. Image size taken 1200x800. Recursive guided filter improve He[5] algorithm which taken much time, our algorithm is 100 times faster than He[5]. Recursive guided filter successfully remove halo effect from haze image and maintain its visibility. Many algorithm based on refine transmission map which result unnatural image. If dense haze present in scene than resultant image look unnatural.

V. CONCLUSION

Recursive guided filter improve dehazing algorithm by refine dark channel prior and reduce the computation cost as compare to other dehaze algorithm. fining dark channel prior image successfully reduce halo effect and then refine dark channel image with recursive guided filter maintain visibility of dehaze image. by adjusting patch size in dark channel prior , also control halo effect.

As computation time is very less, this algorithm can be implement on hardware to used for real time application like object tracking, weather broadcast, video surveillance , security monitoring and many more.

VI. REFERENCE

[1] Srinivasa G. Narasimhan, Shree K. Nayar, "Contrast Restoration of Weather Degraded Images", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 25, no. 6, pp. 713-724, 2003.

[2] Mukhopadhyay, S., & Tripathi, A. K. (2015). Combating Bad Weather Part II: Fog Removal from Video. *Morgan & Claypool*, *7*(2), 1-86

[3] Mukhopadhyay, S., & Tripathi, A. K. (2014). Combating Bad Weather Part I: Rain Removal from Video. *Synthesis Lectures on Image, Video, and Multimedia Processing*, *7*(2), 1-93.

[4] Chen, Mengyang, et al. "Single image defogging." Network Infrastructure and Digital Content, 2009. IC-NIDC 2009. IEEE International Conference on. IEEE, 2009.

[5] K. M. He, J. Sun, X. O. Tang. Single image haze removal using dark channel prior. In *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, IEEE, Miami, FL, USA, pp. 1956–1963, 2009.

[6] R. Fattal. Single image dehazing. *ACM Transactions on Graphics*, vol. 27, no. 3, Article No. 72, 2008.

[7] Xu, Zhiyuan, Xiaoming Liu, and Na Ji. "Fog removal from color images using contrast limited adaptive histogram equalization." Image and Signal Processing, 2009. CISP'09. 2nd International Congress on. IEEE, 2009.

[8] Wang, Yan, and Bo Wu. "Improved single image dehazing using dark channel prior." Intelligent Computing and Intelligent Systems (ICIS), 2010 IEEE International Conference on. Vol. 2. IEEE, 2010.

[9] Yu, Jing, and Qingmin Liao. "Fast single image fog removal using edge-preserving smoothing." Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on. IEEE, 2011.

[10] Shuai, Yanjuan, Rui Liu, and Wenzhang He. "Image Haze Removal of Wiener Filtering Based on Dark Channel Prior." Computational Intelligence and Security (CIS), 2012 Eighth International Conference on. IEEE, 2012.

[11] Cheng, F-C., C-H. Lin, and J-L. Lin. "Constant time O (1) image fog removal using lowest level channel." Electronics Letters 48.22 (2012): 1404-1406.

[12] Xu, Haoran, et al. "Fast image dehazing using improved dark channel prior." Information Science and Technology (ICIST), 2012 International Conference on. IEEE, 2012.

[13] Kang, Li-Wei, Chia-Wen Lin, and Yu-Hsiang Fu. "Automatic single-image-based rain streaks removal via image decomposition." Image Processing, IEEE Transactions on 21.4 (2012): 1742-1755.

[14] Tripathi, A. K., and S. Mukhopadhyay. "Single image fog removal using bilateral filter." Signal Processing, Computing and Control (ISPCC), 2012 IEEE International Conference on. IEEE, 2012.

[15] Tripathi, A. K., and S. Mukhopadhyay. "Single image fog removal using anisotropic diffusion." Image Processing, IET 6.7 (2012): 966-975.

[16] Wei, Sun, and Han Long. "A New Fast Single-Image Defog Algorithm." Intelligent System Design and Engineering Applications (ISDEA), 2013 Third International Conference on. IEEE, 2013.

[17] Im, Jaehyun, et al. "Dark channel prior-based spatially adaptive contrast enhancement for back lighting compensation." Acoustics, Speech and Signal Processing (ICASSP), 2013 IEEE International Conference on. IEEE, 2013.

[18] Sahu, Jyoti (2012) Design a New Methodology for Removing Fog from the Image International Journal 2.

[19] Matlin, Erik, and Peyman Milanfar (2012)Removal of haze and noise from a single image IS&T/SPIE Electronic Imaging. International Society for Optics and Photonics.

[20] K. M. He, J. Sun, X. O. Tang. Guided image filtering. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 35, no. 6, pp. 1397–1409, 2013.