A FAST METHOD OF FOG AND HAZE REMOVAL

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ABSTRACT

Fog and haze degrade the quality of preview and captured image by reducing the contrast and saturation. As a result the visibility of scene or object degrades. The objective of the present work is to enhance the visibility, saturation, contrast and reduce the noise in a foggy image. We propose a method that uses single frame for enhancing foggy images using multilevel transmission map. The method is fast and free from noise or artifacts that generally arise in such enhancement techniques. A comparison with existing methods shows that the proposed method performs better in terms of both processing time and quality. The proposed method works in real time for VGA resolution. The proposed work also presents a scheme to remove fog, rain and snow in real-time.

Index Terms**—**Fog removal, snow removal, rain removal, dark channel prior, temporal filter

1. INTRODUCTION

Outdoor scenes are often affected by fog, haze or smog. Often we like to capture such landscapes as fog or haze adds significant visual pull. But, a user may like to capture a clearer picture by reducing the effect of fog especially when the density of fog is too high. In driving scenarios, dense fog reduces the visibility and may cause road accidents. It also affects flight take-offs and landing. Hence, reducing the effect of fog or haze in preview frames and captured images may add significant value in our daily life. In this work we propose an enhanced method of reducing fog or haze from a captured image or from a low resolution camera preview.

Poor visibility due to fog or haze is caused by suspended particles in the atmosphere. The incoming light from a scene or object is scattered due to these particles and hence is attenuated till it reaches the camera. As a result, both saturation and contrast of the captured image reduces significantly. A number of methods are reported in literature for reducing the effect of fog from image by using single or multiple frames [1]-[4]. Sahu [1] proposed a hue preserving method of enhancing foggy image. Tan [2] suggested a method of local contrast enhancement for fog removal. Both the above methods do not use any physical model of degradation and in many cases produce over saturated outputs. Xu, et al. [3] proposed a method on contrast limited adaptive histogram equalization or CLAHE. In this method, the image is converted to HIS color space and CLAHE performed on the intensity component and the result is converted back to RGB color space. Again, since this method is not based on any physical model, the output is not satisfactory for all the images. Munira et al. [4] calculated the transmission map assuming depth of the image as a function of blur. Fattal et al. [5] proposed transmission map based on independent component analysis and showed better enhancement of foggy images. But these methods do not produce good quality output for high fog density.

There are few methods based on multiple images at multiple weather conditions or multiple images with different degree of polarization. For example, Narasimhan et al. [6] used multiple images at different weather conditions to get a fog free image based on atmospheric scattering. However, the method produces inconsistent results since atmospheric scattering also depends on wavelength of incident light. Zhang Tao et al. [7] proposed a method using multiple images captured at different weather conditions. In their approach, they calculated airlight and transmission map by establishing relation between two images. They removed the fog using physical model by substituting airlight and transmission. The limitation of this method is the availability of same scene or image at different weather.

He et al. [8] proposed dark channel in the neighboring pixels window to estimate the airlight and transmission map followed by soft matting to refine the image. The method significantly enhances the quality of hazy images. The main limitation of this method is the computationally expensive matting technique which takes time in the magnitude of tens of seconds for processing an image of resolution 640x480. Also, the method uses a fixed size block for generating transmission map which cannot ensure edge preservation and as a result the sharpness of the image degrades.

In the present work, we propose an enhanced image refinement technique which is based on a dark channel prior and airlight calculation. The method uses multi-level transmission maps using different block sizes followed by cross bilateral filtering for better noise removal and edge enhancement. The major contributions of the paper are

- Computation of transmission map with multiple block sizes to avoid soft matting and hence reducing the processing complexity
- Computation of transmission map based on saturation map for better compensation of saturation.
- Temporal filtering of the radiance images with different block sizes to remove noise.
- A modified method to compute dark channel prior
- A scheme of streaming fog, rain & snow free images

2. METHODOLOGY

A foggy image may be represented as [8]

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

where I is intensity of the pixel, J is original scene radiance, A is global Airlight, and t is medium of transmission describing the portion of light that is not scattered and reaches the camera. Airlight A is the result of scattering of light from scene or object. A typical fog removal method involves estimating A to find original scene radiance. The block diagram of the proposed method is shown in Fig.1. The method computes dark channel prior [8] and saturation map to find transmission map for three different block sizes. Each component of the proposed method is explained in detail in the following sections.

2.1. Calculating dark channel prior and airlight

He et al. [8] proposed dark channel prior based on the observation that at least one color channel has some pixels whose intensity values are very low and close to zero. In the current work it is computed as (2)

$$J^d = min_{y\in\Omega(x)}\left(\left(1-\sigma_{rgb}\right) * \mu_{c\in\{r,g,b\}}\big(J^c(y)\big)\right) \quad (2)$$

where J^c is a color channel of J, μ is a mean and σ_{rgb} is standard deviation of r, g, b intensity values and $\Omega(x)$ is a local patch centered at x.

Fig.2 shows the comparison of dark channel prior results generated by proposed method with respect to the method proposed by He et al [8]. In the present work, we consider top 1% pixels in computing airlight and find the pixel which has maximum value of J^d in its dark channel among the pixels based on equation (2). The value of I at that pixel is considered as airlight for the proposed method.

2.2. Calculating transmission map & radiance map

It is observed that the saturation of color in a foggy image decreases with the density of fog which in turn depends on depth or distance of the object [12]. In the proposed method we combine saturation map and airlight to get a more accurate transmission map and clearer image. The proposed transmission map is calculated as (3)

$$t = 1 - f(S)\left(min_{y\in\Omega(x)}\left(\left(1-\sigma_{rgb}\right) * \mu_{c\in\{r,g,b\}}\left(\frac{I^c(y)}{A^c}\right)\right)\right) \quad (3)$$

where $f(S)$ depends on the saturation of the input image at x. It is expressed as

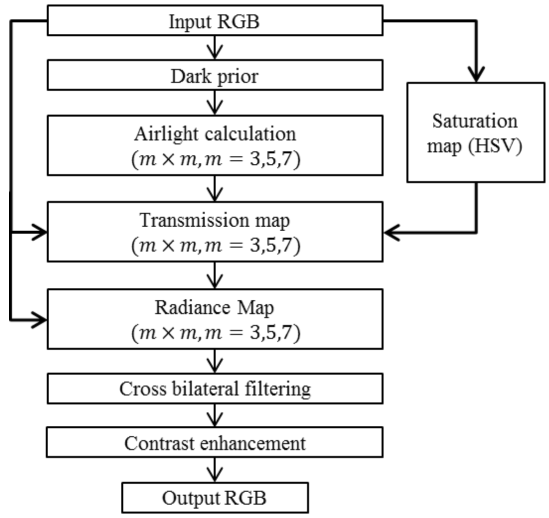

Fig.1. Block diagram of the proposed method

Fig.2. Dark channels comparison (a) proposed (b) He et al. [8]

$$f(S) = 0.8 - (0.2 * S) \quad (4)$$

where S is saturation of the pixel ($0 \le S \le 1$). We map saturation value of the pixels to $f(S)$ to enhance the output as we observed lesser saturation in object that are far away and have more fog. If the saturation is less, $f(S)$ will be more and vice-versa. This helps to remove inconsistent color patches in the output.

As suggested in [8], we estimate scene radiance as

$$J(x) = \frac{I(x)-A}{max(t(x),t0)} + A \quad (5)$$

where $t0$ is a factor to restrict the noise level.

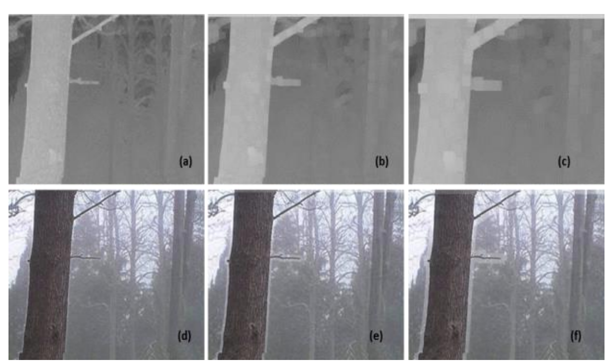

Fig. 3. Transmission and radiance maps for different blocks (a) & (d) $\mathbf{3 \times 3}$, (b) & (e) $\mathbf{5 \times 5}$, (c) & (f) $\mathbf{7 \times 7}$

It is observed that the transmission map based fog removal approach creates blocks and artifacts along the edges. To avoid such kinds of artifacts, soft matting was proposed by He et al. [8] as the foggy image model closely matches with image matting. But, soft matting involves complex processing and hence takes more time to remove artifacts. In the present work, we avoid soft matting by computing 3 transmission maps using 3 different block sizes $(3\times 3,\ 5\times 5,\ 7\times 7)$ and generate radiance map for all block sizes followed by cross bilateral filtering. The transmission maps and corresponding radiance images are shown in Fig. 3. The transmission map calculated for a specific block size shows block artifacts. For a bigger block size the effect is even more though it reduces noise. It can be seen that the radiance image for block size 7×7 generates more artifacts in the image along the edges as compared to 3×3. Whereas the noise level in 7×7 is less as compared to 3×3. Hence, in this work, we combine these three radiance images using cross bilateral filtering to achieve a better quality radiance map.

2.3. Cross bilateral filter to merge Images

This approach of ours reduces noise and eliminates the need for soft matting thus improving the time required for processing. Cross bilateral filter does weighted averaging of pixels across multiple frames (radiance image) obtained in the previous section. The radiance map corresponding to $\mathbf{3\times 3}$ block is considered as a reference as it preserves most of the edge or gradient information in the image. The filtering is performed on intensity (Y) of the radiance image. It is defined in [9] as (6)

$$Y_{ij} = \frac{1}{K}\sum_{k=1}^{N}\left\{e^{\left(\frac{-\left(Y_{ij}(3\times 3)-Y_{ij}(k1\times k1)\right)^2}{2\sigma_m{}^2}\right)}Y_{ij}(k1\times k1)\right\} \quad (6)$$

where Y_{ij} is the filtered output at (i,j) pixel location, N is the number of frames, $k1$ indicates block size, σ_m is a constant and K is normalizing factor given by (7),

$$K = \sum_{k=1}^{N}\left\{e^{\left(\frac{-\left(Y_{ij}(3\times 3)-Y_{ij}(k1\times k1)\right)^2}{2\sigma_m{}^2}\right)}\right\} \quad (7)$$

The value of σ_m depends on the characteristics of noise [9]. The weights depend on deviation of pixel of current frame from the pixel of reference frame. If the deviation is less the weights tend to become equal, otherwise they are different.

2.4. Contrast enhancement

As discussed earlier, presence of fog or haze in the image reduces the contrast of captured image. Hence, contrast enhancement is performed to restore the contrast. Since the noise component is reduced in the previous step (using temporal filtering) the contrast may be enhanced without enhancing the noise. The contrast enhancement as shown in (8) as

$$I(x,y) = \frac{1}{1-m^{\gamma}+\left({}^{m}/_{r(x,y)}\right)^{\gamma}} \quad (8)$$

where m is a threshold, $r(x,y)$ is input intensity and γ is contrast enhancement factor to produce output $I(x,y)$. Based on empirical observation using a number of images we assumed m to be 0.8 times the mean intensity of the image and $\gamma = 2.0$ in the present work.

3. RESULTS & DISCUSSIONS

3.1. Output image quality

The proposed method of fog removal is evaluated on a set of 150 images. A few sample images are shown in Fig. 4. The output images were enhanced significantly in terms of fog removal, saturation and contrast enhancement. As the generation of transmission map is based on saturation component, the degradation of the color saturation of image is appropriately compensated at most of the places. The output quality is compared with He et al. [8] in Fig. 5 through measurable parameters, edge visible gradients and edge descriptors as proposed in [12]. It can be seen that the proposed method provides better edge enhancement as compared to the method in [8].

3.2. Processing time

Table I shows the performance comparison of the proposed method for desktop processor with respect to the other methods. From the data it is evident that computational complexity of the present method is less as compared to other techniques. The proposed method is optimized further for mobile device (Samsung Galaxy S6 , Exynos 7420, Quad-core 1.5 GHz Cortex-A53 & Quad-core 2.1 GHz

Fig.4. Comparison of results (a) input (b) He et al. [8] (c) proposed method

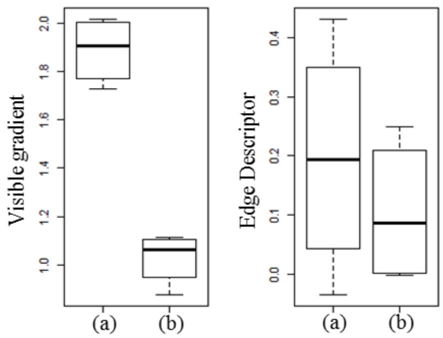

Fig.5. Comparison of (a) proposed method & (b) He et al. [8]

Cortex-A57) and the performance was enhanced further using Single Instruction Multiple Data (SIMD) instruction set. The performance on mobile device is shown in Table II. It can be seen that the proposed method works at 25 fps (40 msec) for VGA quality resolution. Hence, for such resolution real-time haze free streaming is possible thus finding the applications in vehicular and surveillance systems.

Table I: Comparison of processing time (Intel Core i7 3630QM 2.40 GHz, Image resolution (600×400)

Tan [2]	He et al. [8]	Proposed method
42.857 sec	2.142 sec	0.105 sec

Table II: Performance of the proposed method in mobile device (Samsung Galaxy S6, Exynos 7420, Quad-core 1.5 GHz Cortex-A53 & Quad-core 2.1 GHz Cortex-A57)

Image size (pixels)	Processing time (sec)
(640×480)	0.040
(320×240)	0.026

As the proposed method works faster for smaller resolution we made an attempt to realize it on mobile camera preview in real time so that a foggy scene can have a better visual quality when viewed on the camera preview. Another advantage of the proposed method is that, it is capable of working with multiple frames of preview or video as we use temporal filtering instead of soft matting. Hence, the method is capable of enhancing the preview in presence of snow or rain as well. During rain or snowfall the distant objects become hazy and rain or snow droplets are visible on relatively closer objects of the preview. As the snow and water droplets appear at different positions in different frames, temporal filtering helps reducing the visibility of such droplets in the output frame. The haze in higher depth regions is reduced in the same way as we remove fog in the present work.

3.3. Real-time haze removal on mobile camera:

The proposed method is tested on mobile device (Samsung Galaxy S6) for real-time processing of input video streams. The preview is resized to VGA quality to achieve real-time performance (25fps). Since the quality of foggy frames is poor in terms of contrast and saturation, resizing does not severely degrades the final output quality. The proposed scheme is shown in Fig. 6. Fig. 7 shows an example of snow removal from video frames. A set of three input frames and the enhanced output frame (extracted from input and processed video clips) are shown in Fig.7.

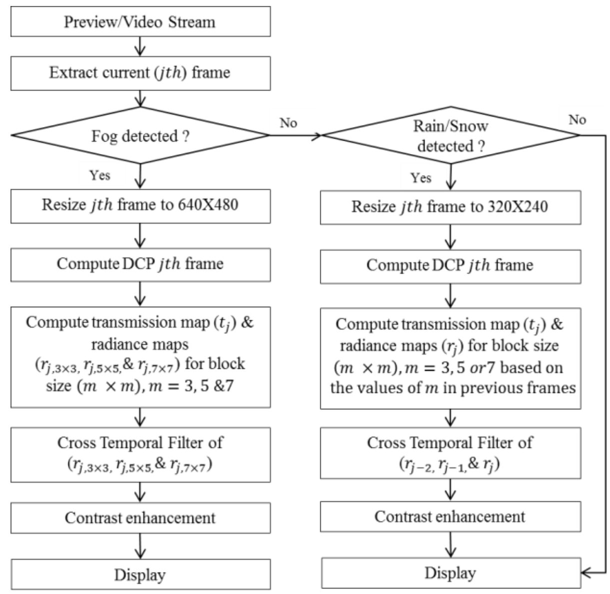

Fig.6. A Scheme of rain/snow removal from video stream

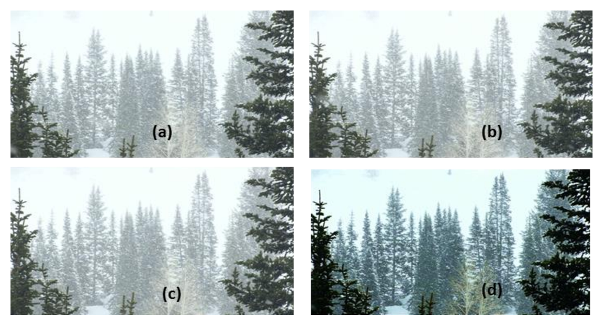

Fig.7. Snow removal from video: (a), (b), & (c) are input frames and (d) is output frame

4. CONCLUSIONS

An enhanced fog removal technique is proposed. The method is effective in fog or haze removal so as to produce a better output as compared to existing fog removal techniques. Both saturation and contrast of the image are enhanced without adding any noise or blocking artifacts in the image. The proposed method uses transmission maps based on multiple blocks and temporal filtering, which helps to remove some of the noise generated due to fog. Though the proposed method is faster as compared to other existing techniques, real-time fog or haze removal is still a challenge for HD or better quality preview frames. We are trying to enhance the performance further by using heterogeneous computing platform consisting CPU and GPU.

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