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A REVIEW ON VISIBILITY RESTORATION OF DEGRADED IMAGES UNDER INCLEMENT WEATHER CONDITIONS

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ABSTRACT

Outdoor Images captured under inclement weather conditions are degraded by various atmospheric particles, which vary in size and concentration. To restore the visibility of the degraded images, various state-of-the-art algorithms were developed for the past decade. In this paper, an overview of various research works carried over the past decade related to static weather conditions like Haze, fog and dynamic weather conditions like rain are investigated. Also, the merits and demerits of each algorithm along with the challenges in this area are focused.

Keywords: haze, fog, rain streak, air-light, attenuation.

1. INTRODUCTION

Inclement weather condition causes the outdoor images to degrade. This is due to various atmospheric particles that scatters and attenuate the light from the scene. Scattering due to air molecule is minimal, when compared with other atmospheric particles, due to the small size of air molecule relative to the wave length of visible light. As shown in Figure-1, weather is classified as static and dynamic. Inclement weather conditions are caused by (i) haze, which is an aerosol suspended in the atmosphere, (ii) fog, that evolves as water droplets at ground level when the humidity in the atmosphere reaches saturation, (iii) cloud, existing as water droplet at troposphere (iv) rain, water drops randomly distributed in space and their high velocity form rain streaks and (v) snow, a frozen rain [1].

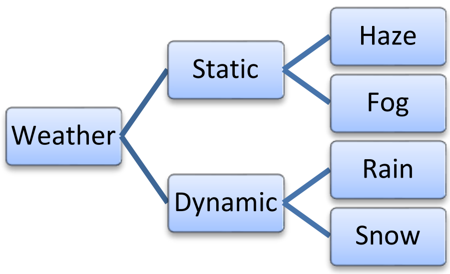

Figure-1. Classification of weather.

Static weather conditions like haze and fog causes the perceptual quality of the image to degrade. Most of the research work carried for removal of haze or fog can be classified into (i) enhancement and (ii) Restoration based methods. Since the thickness of the haze or fog depends on the depth information, the enhancement based method fails to restore the image and also retain the true color of the image. Also, over enhancement will lead to saturation of pixels. Most of the research work is based on restoration based method which follows the physics based haze image model. According to Koschmieder's law, the haze or fog image can be mathematically represented as follows,

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

where, I(x) is the intensity of the hazy image at 2D location (x, y), J is the scene radiance or the haze free image to recover, A is the atmospheric light, which is commonly assumed to be globally constant, t is the transmission of light from the scene point to the camera, which can be expressed as $t= e^{-\beta d(x)}$, where β is the atmospheric scattering coefficient, d is the distance between the scene and the camera.

From the haze image model, we can confirm that the degradation is due to (i) *direct attenuation* of the light as it passes through the atmosphere from the scene to the camera which is specified as J(x).t(x) in Eq.1,and (ii) *air-light*or*atmospheric veil* is due to scattering of light from the haze or fog particles and portion of the scattering light reaches the camera which is specified as A(1-t(x)) in Eq.1, Attenuation reduces the contrast and air-light or atmospheric veil adds whiteness to the captured hazy image. The Equation (1), can be rewritten as

$$I(x,y) = L\,\rho\, e^{-\beta d(x,y)} + L\,(1-e^{-\beta d(x,y)}) \quad (2)$$

where, L is the atmospheric light, ρ is the reflectance of an object in the image as shown in Figure-2.

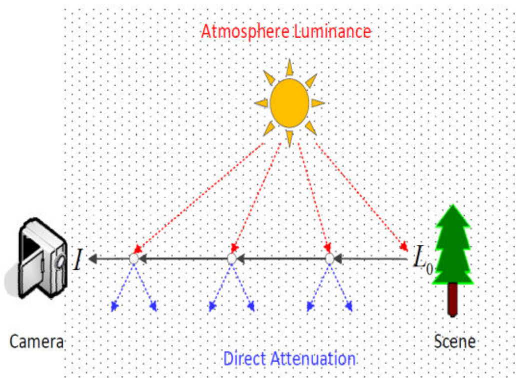

Figure-2. Picture describing the formation of haze or fog images in optical model.

Dynamic weather conditions like rain and snow also degrades the perceptual image quality. Raindrops are randomly distributed in the atmosphere and as they fall with high velocity they form rain streak. Size of the rain drop varies between 0.5 and 10 mm. 95% of rain drops are spherical in shape. The shape of the rain drop undergoes distortion and falls as rain streak. The shape of the undistorted rain drop is defined as

$$r(\emptyset) = a\left(1 + \sum_{n=0}^{10} c_n cos(n\emptyset)\right) \tag{3}$$

where, as is the radius of the undistorted sphere, $C_n$is the shape coefficient, ϕ is the polar angle of elevation with ϕ=0, corresponds to the direction of the rainfall [2].

The visible light reaching the camera produces high intensity due to internal and specular reflection along with refraction from the raindrop. So raindrops on the captured image are brighter than the background. Also brightness is independent of the background. As the raindrop falls, the irradiance captured by the camera produces a “delta signal” in time domain [3].

2. FRAMEWORKFORREMOVAL OF HAZE

The research work was carried initially, with multiple images of the same scene taken at different weather conditions or at different angles. For the past few years, most of the work is carried using single image. Restoring the static weather degraded haze or fog images can be performed in two stages namely (i) depth estimation and (ii) scene restoration. Thickness of the fog depends on the depth information. So, in the literature, for removal of haze or fog depth estimation is determined.Most of the state-of-the-art algorithms for the past decade is used to estimate the parameters like depth, transmission and atmospheric light to restore the degraded image as shown in Figure-3.

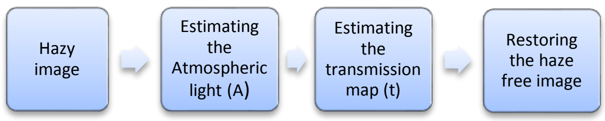

Figure-3. Framework for removal of Haze or fog from images.

3. SURVEY ON REMOVAL OF HAZE FROM WEATHER DEGRADED IMAGES

During the last decade, research related to visibility restoration due to static and dynamic weather conditions has undergone rapid development. Tripathi [4-5]published a comprehensive survey of the removal of haze and rain in2012. The intension of our article is to cover the past and current development in this area of research.

In the literature for fog or haze removal, most of the paper is analyzed in time domain. Initial research was carried using multiple images, but in practice, the use of the algorithm is restricted, so most of the researchers concentrate on single image.

Narasimhan and Nayar[6] proposed a method for removing haze by using multiple images of the same scene taken under different weather conditions. Depth was estimated using the intensities obtained from the two images of same scene. Using depth information, the clear haze free image was restored. The drawback of this method is to rely on changes in the weather condition to obtain multiple images.

Similarly, Schechner[7] proposed a method using multiple images taken with different degree of polarization. The above method also fails, because of the acquisition of additional information.

To resolve using a single image, an assumption or prior knowledge is required, due to the vagueness between air-light and attenuation which holds for every pixel.

Fattal [8] proposed a method using single image. Fattal’s assumption was object surface shading and transmission signals are uncorrelated. By using independent component analysis (ICA) transmission was estimated. Later, color was inferred using Markov random field (MRF).The proposed method is based on the color and thus cannot deal with gray scale images. This method is computationally intensive.

Tan [9] proposed a method using single image which works for both color and gray scale images. Tan estimated the atmospheric light from Eq. 2, by substituting d=∞, so that the equation reduces to I(x,y)=L, which was obtained from sky intensity of the outdoor hazy image. Tan’s assumption was haze free clear image have better contrast than the hazy image. Also, except at depth discontinuities the air-light smoothly varies across small patches. Tan removed the haze by maximizing the contrast of direct transmission keeping air-light to be smooth. Further, Markov random field was used to regularize the result. This method is simple but halos were found at depth discontinuities. Also some output images were obtained with large saturation values.

Tarel [10] introduced a fast restoration method for fog removal based on filtering approach using single image. White balance is performed prior to visibility restoration algorithm. Tarel’s assumption was air-light is a percentage of the difference between the local average and the local standard deviation of whiteness. This method is fast, but not suitable to restore images with large scene depth because median filter is used which is not an efficient edge preserving smoothing filter.

Later, Tarel [11-12] proposed visibility enhancement algorithms for removing homogeneous and heterogeneous fog from images. They have focused on road scene images and the algorithm is developed for advanced driver assistance system. They have created a database (FRIDA) consisting synthetic images with and without fogwhich will be useful for researchers working in this area.

KaimingHe[13] proposed a method based on a key observation on haze free outdoor images known as dark channel prior. According to dark channel prior, “in

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most of the non-sky patches, at least one color channel has very low intensity at some pixels". Dark channel prior is defined as

$$J^{dark}(x) = \min_{c\in\{r,g,b\}} \left(\min_{y\in\Omega(x)} (J^c(y))\right) \quad (4)$$

Where J^c is a color channel of J and Ω(x) is a local window centered at x. Assuming, transmission within the window is constant, applying dark channel prior to Eq.1, where J haze free radiance tends to zero, the equation reduces to

$$t(x) = 1 - \left(\min_{c} \left(\min_{y \in \Omega(x)} \left(\frac{I^c(y)}{A^c}\right)\right)\right) (5)$$

Atmospheric light is obtained by taking the top 0.1% brightest pixel from the dark channel. This method is the best haze removal algorithm, but fails when the scene objects are bright similar to atmospheric light. Estimating the brightest pixel as atmospheric light causes the reconstructed images dimmer. To avoid over saturation, large window size (15 x 15) is considered which leads to higher computational cost. Also halos are produced at depth discontinuities, since transmission t is assumed to be constant within the window. To refine the transmission map, a high computational soft matting algorithm was developed. To reduce the halos, Kaiming He [14], later introduced guided filter which is a fast edge preserving smoothing filter. But the halos are not completely removed using guided filter, since it is local filter. So many researchers extended the work of KaimingHe[13], to refine the transmission map using global filter.

Zhengguo Li[15]introduced weighted guided filter which inherits the advantage of both global and local smoothing filter which effectively used toremoves halo from images.

Tripathi [16] proposed a method by estimating the airlight using dark channel prior and further refining using anisotropic diffusion. This method showed comparatively better results, however the drawbacks of dark channel prior method is not completely resolved.

DubokPark[17] proposed a method based on dark channel prior. The author used Weighted Least Square (WLS) edge preserving smoothing filter to reduce halos. It is an extension work of Kaming He's work [13].

Zhenwei Shi [18] considered the atmosphere to be inhomogeneous and carried work by considering the scattering coefficient βat varying parameter depending on the density of the aerosol. Zhenwei extended KaimingHe's[13] work by finding the dark channel followed by refining transmission using guided filter. In order to remove halos present and also to perform colour correction especially near sky region, the author automatically detected sky region and performed colour correction by suitably refining transmission.

Shiau [19] proposed a method to eliminate the drawback of finding the highest intensity as atmospheric light by introducing a weighted technique incorporated using dark channel prior to find the atmospheric light automatically. To mitigate the halo artifact, transmission map was refined using difference prior. This method applies small window size, so that the computational cost is reduced.

Ancuti [20] proposed an enhancement based method using multi-scale fusion technique. In this method, two images are derived from a single hazy image by applying white balance and contrast enhancement technique. To preserve the region with good visibility and to combine effectively the information of the derived inputs the important features are filtered by applying luminance, chrominance and saliency weight maps. To mitigate the artifact introduced by weight maps, the approach is designed using Laplacian pyramid representation of the inputs combined with Gaussian pyramids of normalized weights in a multi-scale approach. This approach is based on per pixel fashion instead of window based method to overcome the drawbacks of window based method. Since depth and transmission map are not estimated, this approach is fast when compared with previous state-of-the-art algorithms, but fails to enhance heterogeneous hazy image.

YuanyuanGao[21] proposed a method which is based on the concept of photographic developing. When negative of the image is rectified, contrast and saturation can be improved. This is an enhancement based method which works on negative correction.This method fails to give good results, with foggy images which are more opaque than hazy images. Also it is not suitable for hazy images with non-uniform illumination.

Jing Zhang [22] proposed a method to remove haze from night time hazy images. Since the brightness of the image is poor with non-uniform illumination, light intensity is estimated and enhanced. Colour correction is performed for the enhanced image and finally haze is removed using dark channel prior.

Z.Wang [23] proposed a fast dehazing algorithm by deriving two course transmission maps from hazy image. The course transmission map is obtained by applying patch based dark channel prior and another image by applying point based dark channel prior. Both derived images are converted from spatial to frequency domain using fast wavelet transform (FWT). Since patch based derived image contains block artifact which contains unnecessary high frequency components, it is filtered by passing through low pass filter. Similarly, high pass filter is used to extract details from point based dark channel prior. Finally the two filtered image is fused and IFWT is performed. Post processing is performed to increase the sharpness of the dehazed image.

Huang [24] proposed a method to focus on sandstorm images. The atmospheric particles absorb blue hue of the spectrum so that the captured sandstorm image will feature prominently with yellow or orange haze. Dark channel prior fails to dehaze sandstorm images. The drawbacks of the dark channel prior are rectified in this approach. Mitigation of halo artifact is done by applying a median filter to preserve the edge and refining the transmission map by using adaptive gamma correction.The

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color distortion is rectified by analyzing the average intensities in each color channel by using gray world assumption. Finally the restored image with color correction shows a high quality haze free image.

Aliaksei Makarau[25] proposed a method using multispectral imagery. For satellite calibrated and un-calibrated multispectral data, inhomogeneous haze detection was performed by calculating haze thickness map using improvement in dark object subtraction method. The limitation of this method is difficult in locating dark object for rare scenes with highly reflective and flat surface.

Weiping Ni[26] proposed a method for removing haze in satellite image using a simple and effective method by using linear intensity transformation. To estimate the parameters for linear intensity transformation, local property analysis like luminance, chrominance and texture properties were used. This method showed good results when compared with state- of-the-art methods, but still an improvement can be focused on discriminating thick haze and large scale white ground targets.

4. FRAMEWORK FOR REMOVAL OF RAIN

Restoring the dynamic weather degraded images like rain and snow can be performed in two stages namely (i) detecting the raindrop or snow from the image and (ii) removal, as shown in figure-4. Since raindrop in the captured images produces an impulse, the intensity variation between successive frames in video is used to identify the rain drop from non-raindrop pixels. Later, the rain affected pixels are replaced by estimating the background intensity. Recently, the research work is carried using single image for removing raindrop which is a challenge for the researchers where no temporal information is obtained from consecutive frames.

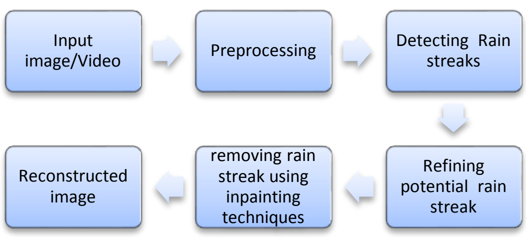

Figure-4. Framework for removal of rain streak from images.

5. SURVEY ON REMOVAL OF RAIN FROM WEATHER DEGRADED IMAGES

Rain drops are randomly distributed in space and causes spatial and temporal intensity fluctuations in the captured video. For the past decade most of the researchers focused on removing rain from video. Recently the researchers have taken the challenge in removing rain from single image were temporal information does not exist. In the literature, rain drops are removed using time and frequency domain.

Garg and Nayar [3] proposed a method to remove rain from video using temporal information. The intensity variations between the two successive frames are used to identify the pixels affected by rain and it is compared with a threshold. To reduce false positive, in the presence of object motion in the scene (dynamic background) the detection process is further refined using photometric constraint. According to photometric constraint the intensity variation or change in intensity is linearly related to background. Further, it is refined to confirm the potential rain streak by using the dynamics of rain which states that rain produces strong directional correlations in video. After identifying the potential rain streak, rain affected pixels are replaced by estimating the average background intensities between successive frames. This algorithm fails, when the rain becomes heavy or lighter to differentiate from the moving object. Also the number of frames required to detect is 30 frames.

Zhang [27] proposed a method combining temporal and chromatic properties. The work was carried based on the observation of the intensity histogram of pixels for a scene with rain which displays two peaks, whereas for a scene without rain displays one peak, for a video taken under static background with static camera. K means clustering is used to classify the two peaks in the histogram. For dynamic background this k means clustering was not adequate, so chromatic constraint is applied. According to chromatic property, the change in R, G, B values of a same pixel location between two successive image frames was approximately same for a scene with rain, but significantly different for a moving object. This method can handle both light and heavy rain as well as rain in focus and out of focus. The drawback of this method is it produces degradation in the perceptual image quality for a video with dynamic background.

Barnum [28] approach was based on removing raindrop in frequency domain. The shape and brightness of a single rain streak is approximated with motion blurred Gaussian model in frequency domain. Complexity in estimating for each rain streak is eliminated using statistical properties, by scaling the Gaussian model with rainfall rate and normalization factor. Finally, frequency domain filter is used to eliminate the raindrops. This method was fast in detecting rain drops and was suitable for scene with dynamic background, but the blurred Gaussian model was suitable only when the rain streaks are prominent.

Brewer [29] proposed a method based on shape characteristics of rain streak. Initially, the intensity variation between the successive frames in video is used to detect the streak. To identify the potential rain streaks, shape characteristic of the rain drop is used, by finding the aspect ratio. To reduce false positive, information about the direction of rain fall is determined using the histogram of streak orientation. After identifying the potential rain streaks, the rain pixels are replaced by the average of the pixel intensity in the previous and following frames. This approach was suitable for scenes with dynamic background, but fails to detect heavy rain when multiple raindrops merge together to produce undesirable shapes.

Bossu [30] proposed a method to isolate the foreground from the background in video, using a classical Gaussian Mixture Model. Since rain and snow are dynamic weather phenomena, the foreground model helps to detect them. To select the potential rain streaks photometry and size is used. Since rain streaks in a frame are oriented in a particular direction, a Histogram of Orientations of rain or snow streaks (HOS) is assessed with the method of geometric moments. HOS is expected to follow a model of Gaussian uniform mixture model. The uniform distribution represents the orientation of the noise; distribution represents orientation of the rain or the snow. To separate these two distributions, an algorithm of expectation maximization is used. This method works well for scene with dynamic background and camera motion, but fails when the rainfall is heavy.

Tripathi [31] proposed a method based on probabilistic model. To discriminate rain pixels from dynamic background they used the intensity variation between successive frames in video and found that the intensity variation at particular pixel in successive frames for a rain affected area was quite different from the intensity variation for a moving object. Intensity waveform for pixels in a rain region was found to be symmetric about the mean when compared with the moving object. Rain pixels are identified from the intensity waveform by estimating the range and spread asymmetry. This method does not depend on shape characteristics but requires around 15 consecutive frames to detect rain pixel from non-rain pixel.

Tripathi [32] proposed another method to reduce the number of consecutive frames by considering the spatiotemporal properties rather considering only temporal properties.

Tripathi [33] proposed a method using meteorological properties. The RGB image is converted to Y-Cb-Cr and rain detection is carried only on Yplane. Global motion compensation is performed for videos taken under moving camera. To obtain the candidate rain pixel change in intensity between consecutive frames are used. To refine the rain pixels meteorological properties like shape and orientation are examined. The shape of the rain streak can be ellipse or rounded rectangle but the aspect ratio is independent of the shape of the rain drop. Area of the rain streak is considered between 10 and 800 pixels, aspect ratio between 0.012 and 0.25 and orientation between 5 and 30 degrees. Finally in painting is performed by taking the temporal mean of I_{n-2} and I_{n+2} pixel intensities. Since this method uses five consecutive frames and also works only on the intensity plane, the complexity and computation time is reduced but fails to use meteorological properties, when the rain is heavy.

Li-Wei Kang [34] proposed a method using single image. Initially the image is decomposed into low and high frequency components using bilateral filter. Further, the high frequency component is decomposed into rain and non-rain pixels by performing dictionary learning and sparse coding. Image is decomposed based on morphological component analysis. The author has successfully separated the rain pixels from non-rain pixels using single image, but this method requires more computational time due to the usage of dictionary learning and sparse coding.

GuiliXu [35] proposed a method to extract rain pixel from video using fast Independent component analysis (ICA). Then, to detect the potential rain streaks, shape characteristics are used.It requires only three successive frames to detect from video using static camera. This method is not suitable for scenes with heavy rain and video taken using dynamic camera.

Changbo Liu [36] used a single colour image to separate rain pixel from non-rain pixel. The color image from RGB is converted to YCbCrcolor space. Since rain pixels are more prominent in Y component when compared with Cb and Cr, the Y component of the image is further processed by determining the direction of rain streak, using Histogram of orientation of edge. Two dimensional directional frequency domain filter is designed, to remove the rain pixel from the Y component. Finally the processed Y component is combined with Cb and Cr. This method is fast in computing, but suitable for color image only.

Varun Santhaseelan[37] proposed a method to detect rain, based on phase congruency from videos. Since video is taken using motion camera, frame alignment is done by registering video frames using phase correlation. Feature extraction is performed using phase congruency and finally potential rain streaks are obtained by applying chromatic constraints.Novel reconstruction is performed, by estimating the actual scene intensity from pixel information, along with spatial and temporal neighbours. This method is suitable for removing rain pixels from video.

Duan-Yu Chen [38] proposed a method which is the extension of Li-Wei Kang method [34] to remove rain from single image. In this method the image is decomposed into low and high frequency component using guided filter to separate rain and non-rain pixels. The rain pixel found in high frequency component along with non-rain textures and edges are further decomposed into rain and non-rain component using dictionary learning and sparse coding. Further to separate rain streaks from high frequency component histogram of oriented gradients (HOG), depth of field, Eigen colour is employed. This method shows better performance in removing rain with non-rain component enhanced. This approach fails to detect rain pixels with less computation time.

Yuan Zhou [39] proposed a method to detect candidate rain streak using optical flow from video. To refine the potential rain streaks hybrid properties like photometric constraints, shape and orientation are used. The scene is restored by weighted composing method. This method fails to detect motion at depth discontinuities because of the use of optical flow.

Xinghao Ding [40] proposed a method to remove rain based on guided L0 smoothing filter from a single image. After obtaining the course rain-free image further refinement is done by minimization operation. This method is found to be effective when compared with the recent methods.

Jin-Hwan Kim [41] proposed a method based on temporal correlation and low rank matrix completion. Initial rain map is obtained by finding difference between temporally warped adjacent frames and current frames. Using sparse representation, the initial rain map is decomposed into basic vectors. Support vector machine is used to classify the basic vectors into rain and non-rain pixels. Reconstruction is performed using Expectation Maximization (EM) based low rank matrix completion.

The proposed algorithm removes rain and snow effectively while preserving the scene. The computation time and complexity is more because of refining rain streak using sparse representation and block matching for rain streak removal.

Shaodi You [42] proposed a method for removing adherent raindrop on windscreen in a video. The challenges in removing adherent raindrops are (i) adherent raindrops are irregular in shapes (ii) they are transparent and the intensity values vary with the environment (iii) the raindrops are blurred due to proximity to the camera (iv) the raindrops generate glare.

Raindrops are detected from the input video based on motion and temporal derivatives. Reconstruction is performed by determining the temporal intensity change for partially occluded raindrops and video completion technique for completely occluding areas. A novel method introduced to detect and remove raindrops from windscreen, but fails to detect with high dynamic raindrops.

Ci Wang [43] proposed a method to remove rain streak in video using anisotropic filter. Since, the performance of anisotropic filter is found to be good for removing structural noise it has been used to remove rain streak from images. The algorithm is more robust to dynamic scenes.

Yu Miao [44] proposed a method to remove rain streak from videos by finding the changes in RGB values between adjacent frames. For refining the potential rain streaks, size and angle filters are used which is based on the properties of raindrops in images. This method uses only two adjacent frames for detection assuming the background to be same.

Jie Chen [45] proposed a method to remove rain streak from videos with high dynamic scenes. To detect rain streak, motion field segmentation is performed initially. Photometric and chromatic constraints are applied for refining the potential rain streaks. Later, rain removal filters are applied on pixels by considering the dynamic properties and motion occlusion clue.

XinweiXue [46] proposed a method to detect rain streak which is based on joint spatial and wavelet domain features. This method is more suitable for rain detection with dynamic background using only two frames.

Chia-Hung Yeh [47] proposed a method using single image. The image is decomposed into high and low frequency part using Gaussian filter. To remove rain streak in low frequency part non-negative matrix factorization is used. Canny edge detection is applied for high frequency part and to preserve the image quality, block copy method is employed. Further, high frequency part is decomposed into rain and non-rain pixels using rain dictionary.

Qi Wu [48] proposed a method to remove raindrops on wind shield for images captured using in-vehicle cameras. The rain drops are identified by analysing the colour, texture and shape characteristic of raindrops in images. To reduce the number of false candidate learning based verification algorithm is used. Reconstruction is performed using in painting tehniques.

HakGu Kim [49] proposed a method that is robust against camera motion. Rain streaks are initially detected using spatial properties like luminance and structure of rain streaks. Gaussian distribution model is used to select the candidate rain streak. Detection is further improved with an advanced temporal property in a block matching process. To find blocks similar to the block that has rain pixels, non-rain block matching algorithm for each block is performed between adjacent frames. Reconstruction is performed by spatio-temporal non-local mean filter. This method uses five adjacent frames for detection.

Shao-HuaSun [50] proposed a learning based method where a single image is decomposed into low and high frequency part. Incremental dictionary learning based on K-SVD is performed for representing high frequency which preserves image details when compared with standard batch mode learning. This method automatically finds the dictionary atoms which are associated with rain patterns by performing image metric of structural similarity index together with a unique learning formulation.

6. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The research work carried for the past decade in removing haze or fog from images shows that most of the algorithm fail to achieve a good trade off between visibility enhancement and computational time. Also most of the state-of-the-art algorithms are validated only for homogenous haze image. Heterogeneous haze images should be considered for evaluation. Since the thickness of the fog or haze depends on the depth information the accuracy in estimating the depth using single image can be improved. Most of the algorithms remove haze but fails, to remove fog which is denser than haze. Also, when there is non-uniform illumination, specifically night time haze images, the state-of-the-art algorithms fail to remove haze. Research work carried for the past decade in removing rain streak from videos has focused mainly to detect the rain pixel from non-rain pixels under static and dynamic background with static and motion camera. In future, the number of consecutive frames should be reduced in video and the algorithm should be designed in such a way that the accuracy in removing should be improved by reducing the blurring artifacts. Most of the algorithms fail to detect the rain pixel based on shape characteristics when two or more rain streak joins together and becomes irregular shape. Generally, the algorithms fail to detect when it is heavy rain with dynamic background. For single image

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were temporal information is not available for detecting rain pixels, the challenges are added.

For removal of rain drops from wind screens the challenges are more due to irregular shape, transparency and out-of-focus blur. Also in future, research can be focused on implementing in real time using hardware such that the computation time can be reduced, so that it finds application in autonomous navigation.

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