An Integrated Computer Vision Based Approach For Driving Assistance To Enhance Visibility In All Weather Conditions

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***Abstract*— One of the key element to increase road safety for surface transport operation is to provide new technological aids to improve the visibility condition across rail and road network. As such both the environmental and human factors are to be considered to achieve higher safety. This paper primarily focuses on a computer vision based solutions which can improve operational capability of road and rail transport under all weather conditions.**

This paper, therefore presents a new physics-based model in the form of transfer function for predicting the environmental degradation to the captured image, as light travels from a source to an observer. This model can essentially compute the variations in environmental irradiance and airlight model used for study of atmospheric scattering in the form of a transfer function. The model is valid for various weather conditions including fog, haze, mist and rain. This model has capability to recover from a single image source the area of maximum attenuation and restoring the contrast of the scene. In addition, the weather condition and the visibility level can be predicted using this approach.

Keywords—scattering, vision, bad weather, radiometry, scene reconstruction, Physics-based vision, defog

I. INTRODUCTION

In poor lightning conditions human vision is badly impaired causing personnel driving vehicles require greater degrees of assistance beyond that is available through high power lightning systems mounted on the vehicle. Presence of fog, rain and snow will further reduce visibility condition due to reflection and scattering of light spectrum by the aerosol particles present in atmosphere. These aerosols scatters light across a wide range of angles that disrupts the vision making it difficult to detect oncoming vehicles. Besides, the bright flickering rain streaks, splashes, fog of various density as well as blurry windshield also contribute to the degradation of scene visibility. This paper presents a computer vision based approach that would be the part of an integrated solution consisting hardware and software for enhanced visibility during poor lightning and bad weather conditions. Typical beneficiaries will include surface transport systems such as automobile and railways for example. Figure 1 below shows how the visibility range could be enhanced by augmenting the computer vision based proposed system for driver assistance.

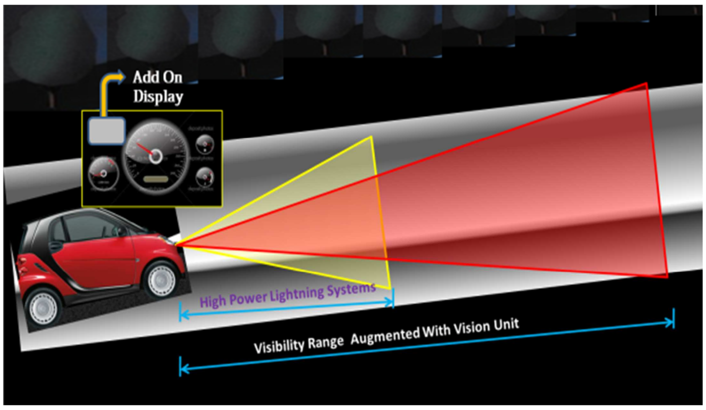

Fig 1: Enhanced visibility range by augmenting the proposed computer vision unit

In contrast to common vision based methods that rely on enhancement techniques to remove the effects of distortions induced by bad weather, the proposed method is based on the physics of radiometry that attempts to calculate the parametric model of degradation process in the captured image and present it in the form of transfer function. As seen the visibility of any driving personnel is severely affected not only due to poor lightning conditions but also due to impaired human vision. The present approach augments facility to see objects in the vehicle path and surroundings by using on-board computer vision unit that calculates the essential parameter for restoration from the present environmental conditions and presents a corrected scene through an alternative display device available in the console. Infact, modeling the scattering of light caused by aerosol particles can help to understand the complex effects of weather on images and hence essential for improving the quality of display of vision systems deployed in outdoor. This paper, therefore presents a physics-based parametric model in form of transfer function for predicting the environmental degradation using the set of captured image and environmental parameters taken during various environmental condition.

Often, vision systems employing general purpose and common CCD/CMOS cameras fail to produce required quality of image resulting in poor quality image or video sequence with graininess, improper color, colored dots, blurriness and low contrast for example. Choice of low resolution and low light cameras could be a possible option when the applications are intended for relatively short distance in nature (of the order of few meters only). When such low lux cameras are used for relatively longer distance of the order of say 10's of meters the resulting grabbed image appears to be of once again of very poor quality. The situation becomes worse for transportation applications which demands longer range of operation (of the order of several 10's of meters or to 100's of meters for railways).The table 1 below shows the relative comparison of minimum level of illumination required by various imaging sensors -

TABLE I. COMPARISON OF IMAGING SENSORS

Imager Type	Visibility Range(in meters)	Min Illumination level To obtain a good quality image(in lux)
CMOS	2-3 m	>10
CCD	4-5 m	1.5-5
LOWLIGHT CAMERA	6-8 m	0.1-1

This has resulted in considerable interest amongst vision communities to study and understand the fundamental issues which has not been given due consideration in the past and of particular interest is the modeling of image formation and subsequent processing of images grabbed during poor environmental condition induced by weather and poor lightning conditions. In bad weather, the presence of aerosols has substantial effects on the images in which surface colors become faint and contrasts are reduced. Such degraded images often lack the desired visual vividness and appeal, but many applications such as Driver Assistance System require robust detection of object or special image features. Infact, the complexity of modeling the traversal of light rays through the atmosphere is well known [10]. One approach to solve this problem is to assume the paths of light traversal to be random and then to apply numerical Monte-Carlo techniques for ray tracing [10]. However, millions of rays must be traced through the atmosphere to accurately model scattering. Complexity of this approach is too high for real time vision based outdoor applications. A different approach for modeling light scattering is the physics-based theory of radiative transfer [9]. The basic idea behind this approach is to investigate the difference between light incident on and exiting from an infinitesimal volume of the medium.

On the other hand, all established dehazing methods reported in the literature can be divided into two categories- bad weather image enhancement based on image processing and bad weather image restoration based on atmospheric scattering model. Recent work in computer vision [2] using simulated images show that it is possible to partially remove such type of degradation in case of simulation [1]. Algorithms have also been developed to recover 3D scene structure and to restore clear day contrasts [2] and colors [2] [3] from bad weather images. Most of this work, however, are based on the atmospheric models of scattering [4] [5] and are only suitable for offline analysis purpose. This paper presents a mathematical function that can be used to predict degradation in the captured image or video sequence in any weather condition using a transfer function based model. This function is then used to restore the bad weather image into the clear day image in real time.

II. MATHEMATICAL MODEL OF IMAGE DEGRADATION

The behavior of light such as intensity distribution and color are altered by the interaction of light with various particles present in the environment. These interactions can be broadly classified as- scattering, absorption and emission [2]. Scattering occurs due to the presence of suspended particles in atmosphere. It is therefore reasonable to classify poor weather into steady (fog, mist and haze) or dynamic (rain, hail and snow) based on their physical properties and the visual effects it can produce in the captured image or video [6].

When the constituent particles are too small (1-10 µm) to be individually captured by camera, the intensity changes produced at a pixel is due to aggregate effect of a large number of droplets within pixel's solid angle. The manifestations of steady weather can now be clearly described through volumetric scattering models of attenuation and airlight proposed by Middleton and Mc Cartney [9]. On the other hand when the constituent particles in the environment falls in the range of (0.1- 10 mm) i.e particles are 1000 times larger than steady weather conditions, it requires a different model that can describe the intensity changes produced by individual particles. Various algorithms have been developed for removing the noise or adverse effects caused by steady weather [1] [2] [3] or dynamic weather [6] from image data. Images captured in bad weather generally show poor contrast and weak color depth. The presence of aerosols in bad weather scenes produces sharp intensity changes in images and videos. In this paper we calculated a parametric transfer function model which will predict the possible degradation in the captured image or video data. This transfer function or model could also be inverted to produce the reconstructed image. Mathematically, the model can be defined as-

$$\mathrm{I_{cap}} = \mathrm{W_m I_{true}} + \mathrm{N}(0, \sigma) \tag{1}$$

where, I_{cap} is the captured image, W_m is the weather predicting transfer function, I_{true} is the clear bright day image and $N(0,\delta)$ signifies the Gaussian noise. W_m is an identity matrix for a clear bright day image

The reconstruction of clear day image can be mathematically described as-

$$I_{reconst} = (W_m)^{-1} I_{cap} + N(0, \sigma) \quad (2)$$

where $I_{reconst}$ is the reconstructed clear day image, $(W_m)^{-1}$ is the inverse of computed transfer function of image degradation, I_{cap} is the captured image, and $N(0,\sigma)$ signifies the Gaussian noise with variance σ.

This model can therefore be applicable for both the steady and dynamic weather, thus providing means to improve the quality of images. This will be beneficial to the navigation, transportation, railways and surveillance systems working outdoor where there is no escape from bad weather. Figure 2. shows a set of sample images to describe the diversity of the situation and complexity of the problem in a qualitative manner.


FOGGY SCENE RAINY SCENE MISTY SCENE HAZY SCENE

Figure 2 : A few typical images showing effects of bad weather

III. FACTORS INFLUENCING VISION

Infact, atmospheric attenuation is primarily caused by scattering of light from suspended particles and absorption [9]. The absorption of light flux by the suspended particles in the atmosphere is of little importance to this work due to the fact that a large number of experimental observation carried out by various researchers has proven that attenuation due to absorption of light in bad weather is difficult to predict. Thus, it is reasonable to assume that "absorption" is an separable function and can only be estimated as a part of overall scattering process. This paper, therefore presents an approach for modeling and estimating the scattering of suspended particles which in turn controls the actual 'absorption' and consequently model the degradation of the captured data and visibility.

Literature shows that scattering of light has a two-fold effect on contrast transmittance. Firstly, light coming from an object of interest and from its background is progressively removed from the viewing path and doesn't reach the camera or the viewer. Such removal of light flux is assumed to follow an exponential law. Bouguer's proposed that, a collimated beam of light containing a flux F_o at the source will have a residual flux at range R from the source given by-

$$F_{dt}(R,\lambda) = F_o e^{-b(\lambda)R} \quad (3)$$

where, b is the scattering coefficient.

Bouguer's exponential law is somewhat limited as it considers only a collimated source of incident energy. This limitation has been corrected by incorporating the inverse square law of diverging beams from point sources.

$$F_{dt}(R,\lambda) = \frac{I_o e^{-b(\lambda)R}}{R^2} \quad (4)$$

where, I_o is the radiant intensity of point source.

The above formulation considered only the intensity of the incident light falling on the scene point. It however doesn't consider the sky illumination and its reflection from the scene. Generally bad weather refers to the situation indicating the sky is overcast. In such cases, the overcast sky model can be used to compensate for environment illumination. The mathematical equation of irradiance will then be modified as-

$$F_{dt}(R,\lambda) = g L_o(\lambda) \eta(\lambda) e^{-b(\lambda)R} \quad (5)$$

where g gives the optical settings of camera, $\eta(\lambda)$ represents the sky aperture and reflectance in direction of viewer, $L_o(\lambda)$ is constant w.r.t ϕ and Θ.

Another important issue is, light cannot come directly from the object or from its immediate background. It has been found that it is scattered in the viewing path. This additional light is called airlight or path radiance. Airlight increases with pathlength and therefore, causes the apparent brightness of a scene point to increase with depth. Mathematically, it is defined as-

$$F_a(R,\lambda) = F_\infty(\lambda)\, e^{-b(\lambda)R} \quad (6)$$

When we consider a bad weather situation, airlight and attenuation both occurs simultaneously, therefore, the total irradiance received by the sensor is the sum of irradiance due to attenuation and irradiance due to airlight.

$$F(R,\lambda) = F_{dt}(R,\lambda) + F_a(R,\lambda) \quad (7)$$

where,

$$F_{dt}(R,\lambda) = g L_o(\lambda)\, \eta(\lambda) e^{-b(\lambda)R}$$
$$F_a(R,\lambda) = F_\infty(\lambda) e^{-b(\lambda)R}$$

Equation (7) can be used to compute the underlying atmospheric degradation. When these parameters are known or can be estimated to a reasonable degree of accuracy this function is then used to reconstruct or detect the true image form captured image during low lightning or bad weather condition.

III. PARAMETRIC BASED TRANSFER FUNCTION MODEL

For simplicity let us consider a unit volume of space at point O of which contains a suspension of scatterers as shown in Figure 3. Now let us allow a collimated beam of nearly monochromatic light be projected along the X axis so that is incident on the unit volume and the luxmeter (detector of radiant flux) be located at point D. This will give the current illumination level of the light source. The X axis and line OD form the observation plane or scattering plane.

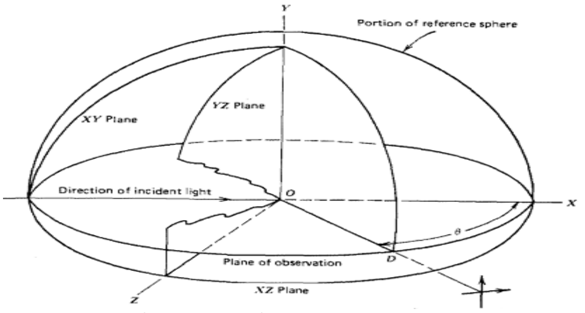

Figure 3: Process of scattering of light beam along X axis by a suspension of scatteres at point O and perceived illumination measured by luxmeter at point D

The measured radiant flux in the absence of scatterer will give the scene irradiance at a situation analogous to clear bright day condition. The scene irradiance measured in presence of scattering screens would be the attenuated scene irradiance. From this, the scattering coefficient (*b*) is calculated by taking the ratio of original light intensity to attenuated scene intensity.

$$\text{scattering coefficient } b = \frac{\text{Scene Irradiance}}{\text{Attenuated Scene Irradiance}} \qquad (8)$$

The correctness of the mathematical model is established by capturing the image of the scene at the above used *'d'* values and measuring the scene irradiance of different depth images. Identical values of the scene irradiance proves the correctness of mathematical model. With this we can establish an appropriate transfer function that will predict the amount of degradation happening to captured image or video during bad weather conditions. Mathematically, the transfer function (W_m) will now be defined as,

$$W_m = \frac{F_o(\lambda)}{F_{dt}(R,\lambda) + F_a(R,\lambda)} \qquad (9)$$

where, $F_{dt}(R,\lambda)$, $F_a(R,\lambda)$ and $F_o(\lambda)$ are defined above.

A. *Experimental Setup And Data Analysis*

For the purpose of validation of the concept model described earlier an experimental setup is designed and fabricated to simulate the true process of atmospheric scattering to the extent it is possible in a controlled environment. This will provide necessary understanding regarding the effects of scattering on the captured images and the quantum of changes in scattering which could be the result of varying weather conditions. It is well understood that such degradation are attributed by the change in size and concentration of aerosol particles presence in atmosphere [4] [9]. The diagrammatic 3D representation of the experiment setup with the inset of actual setup is shown in figure 4. Between the light source and object a movable screen is constructed which changes the illumination level of the scene comprising objects. Thus, the light flux reflected back to the imaging sensor from the object or scene is changed adding noise to the true image. This may be considered analogous to the atmospheric scattering process in the nature, where the aerosol particles in the bad weather condition acts as a screen to the source of light. The changes in the illumination level were measured with a portable light measuring device. Different translucent materials were used as a screen to produce different levels of illumination. The degradation with the change of screen position and different screen materials is measured and the attenuated irradiance of the objects in the scene is calculated at different distance between the camera and source. The distance between camera and object could be varied in the range of 20"(508 mm) to 90" (2286 mm). Data points are selected with the increment of 5" as during experimentation no subtle difference comes in between this range.

The different results drawn below were evaluated using a range of translucent materials for screen such as diaphragm sheet, butter paper and trace paper.

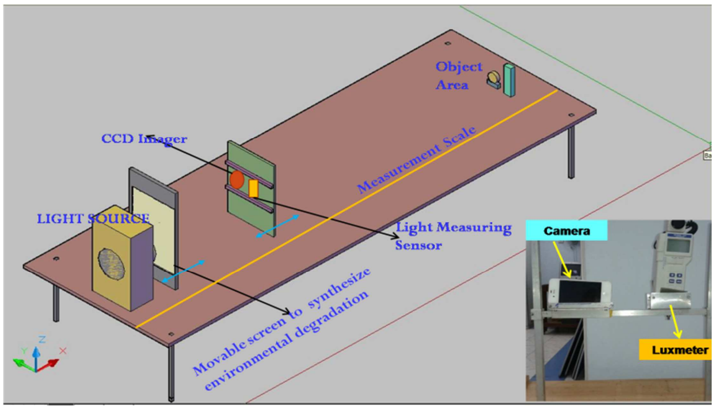

Fig 4: 3D representation of the experimental setup with an inset of the actual setup

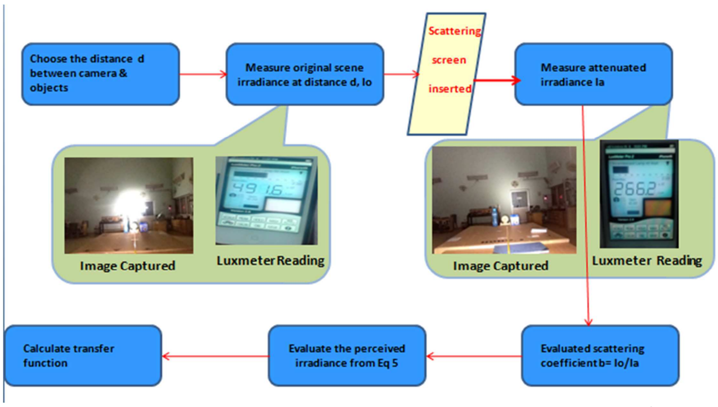

Fig 5: Flow diagram representing the experiment process with snapshot of measured values and images

Scattering coefficient b is calculated using equation (6) for different values of *d* (d= 40" 45" 55" 60" 80"), where *d* is the distance between the camera and objects in the scene. This is shown graphically in Figure 6-

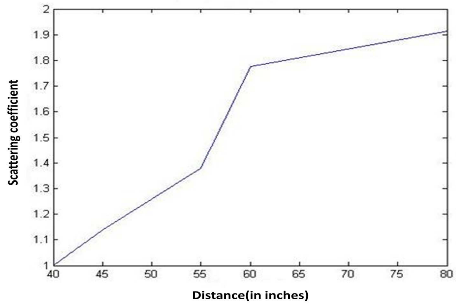

Fig 6: Plot of scattering coffiecient vs distance between camera and objects

These values for different distance are substituted in equation (2), (4) and (5) to calculate the attenuated, airlight and total perceived irradiance. From this, the transfer function of degradation is evaluated that predicts the environmental degradation to the captured image or video and can serve as the potential input to the image restoration of clear day image from the bad weather image. The measured graph are shown in figure 6 and 7:

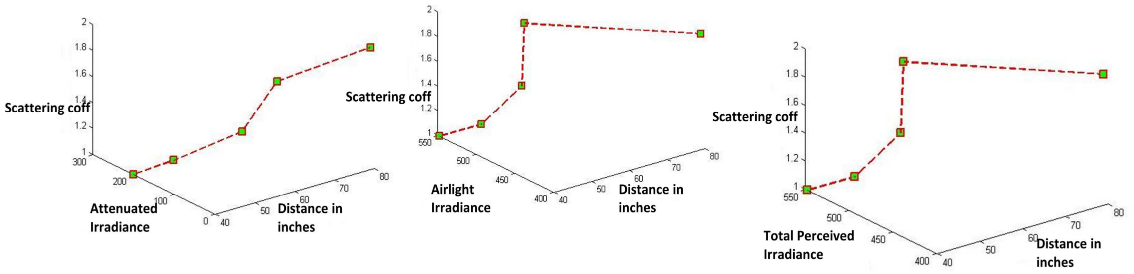

Figure 7: Measured graphs of attenuated , airlight and total perceived irradiance

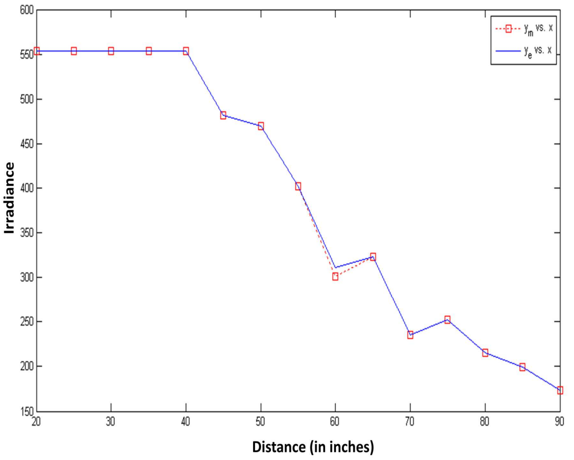

Figure 8: Validating experimental and mathematically calculated perceived irradiance value

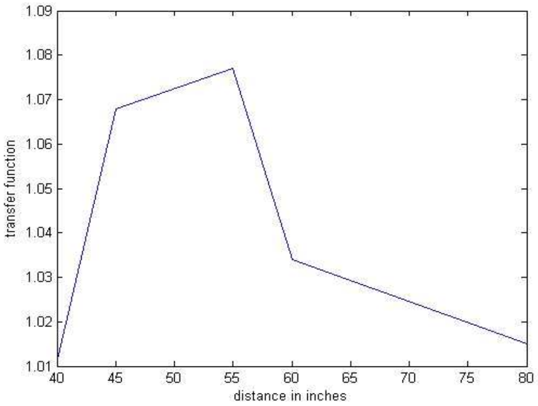

Figure 9: Plot of transfer function w.r.t distance between objects and camera

The transfer function equation of degradation can be modeled as a polynomial given by-

$$W_m = a + bx + cx^2 \qquad (8)$$

where *a*, *b* and *c* varies according to the degradation due to particular scattering screen and x signifies the distance between camera and object. The graph showing the variation in these parameter values with reference to different scattering screen is shown below-

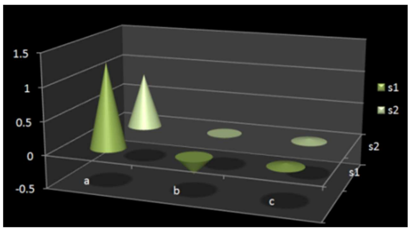

Figure 10: Parameter a, b and c values for different screen s1 and s2

IV. REMOVING WEATHER EFFECTS FROM CAPTURED IMAGES:

It is now possible to develop a simple yet effective algorithm for detection and removal of bad weather effects from captured image data. One might consider the effects of weather conditions as noise and believe that popular image processing techniques can be used to handle these distortions. However, unlike noise, the intensities produced by bad weather aerosol particles have strong spatial structure and depend strongly on background brightness. Furthermore, certain type of scene motions can produce temporal and spatial frequencies similar to a rainy day image, making it hard for conventional image processing techniques to distinguish rain from other signals.

In order to process image data obtained during poor weather condition it is essential that algorithms must distinguish distortions caused by weather effect when compared with other types of aberrations in the received signal. In other words this means that weather effect on image data requires capability too handle wider variation in visual presence of objects or artifacts in the image. The proposed transfer function based approach provide an simple and efficient way of achieving this. This algorithm consists of two main stages. In the first stage pixels affected by bad weather aerosols are identified and use them to segment attenuated regions from the non-attenuated regions. In the second stage weather noise is removed from the affected pixels that lie in the attenuated region of the image. Figure 10 shows the algorithmic flow of presented approach.

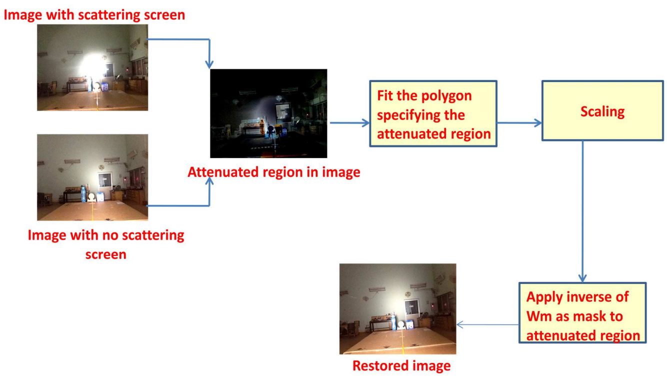

Figure 10: Pipelined restoration algorithm

A. *Recovering Scene Contrast and Wm*

When an image of an object situated behind the function model. An approach for recovering the scene contrast and hence for removing the glow around objects, is to use the Wm computed from real data. Image of objects with scattering screen would be then convolved with the inverse of the Wm to recover the true image of the scene.

This approach is now extended to the transfer function based approach to model the bad weather situation. The goal is to generate a visually realistic bad weather

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[1] Other models like 3rd order polynomial and exponential were also studied with poor Mean Square Error Estimation Compared to 2nd order equation given in (8)

image from a clear day scene. Bad weather effects such as rain, snow and fog created by directly manipulating the original clear day image is done by adding a series of noise is unable to render the actual bad weather condition. The transfer function used to create simulated weather from an experimental setup using distant source under stationary atmospheric conditions produce visibly better results.

Original scene **Simulated bad scene**

Figure 11: (a) Original Scene (b) Simulated Bad Scene

This results in a simplified method to restore scene contrast from a bad weather image using the transfer function of degradation is defines mathematically as-

$$\text{Restored Contrast} = C .* (W_m)^{-1} \quad (9)$$

The screenshot of the restored contrast of the image at various distances from the imaging sensor is shown in figure :

Figure 12: (a) Captured bad Scene (L-R) (b) Restored scene contrast using the proposed model (L-R)

B. Performance Metric

Conventional image restoration algorithms based on image enhancement like histogram equalization, unsharp masking, retinex theory and wavelets based approach to correct or rectify bad weather image offers many challenge due to complexity associated in recovering luminance and chrominance while maintaining color fidelity. Often excessive enhancement of the images leads to saturation of pixel value. Thus, enhancement should be bounded by some form of constraints to avoid saturation of image and yet preserve color fidelity.

Another major point to be considered is that degradation caused by bad weather is that the local image contrast depends strongly on distance between object and camera. These enhancement-based methods may be applied locally, but low spatial frequencies are lost . Therefore, it is necessary to inculcate knowledge of scattering phenomenon and a proper weather model needs to be designed for efficiently removal of weather effects from poor quality images.

The proposed algorithm is compared with other enhancement based algorithms like histogram equalization and its variants, unsharp masking, retinex theory and wavelets. Infact, the contrast gain could then be used as a parameter to assess the performance measure of all these approaches. Contrast gain for all fog removal algorithms must be positive. High contrast gain indicates better performance of the algorithm. It can be described as mean contrast difference between de-foggy and foggy image. If C and C_{fog} are mean contrast of de-foggy and foggy image respectively, then contrast gain is defined as-

$$C_{gain} = \overline{C_{true}} - \overline{C_{fog}} \tag{10}$$

Let an image of size M×N be denoted by X(x, y). Then, mean contrast is expressed as:

$$\overline{C} = \frac{1}{MN}\sum_{y=0}^{N-1}\sum_{x=0}^{M-1} C(x,y) \tag{11}$$

where, $C(x,y) = \frac{S(x,y)}{m(x,y)}$

where, $m(x,y) = \frac{1}{(2p+1)^2} \sum_{k=-p}^{p}\sum_{l=-p}^{p} X(x+k, y+l)$

$$S(x,y) = \frac{1}{(2p+1)^2}\sum_{k=-p}^{p}\sum_{l=-p}^{p} |\, X(x+k, y+l) - m(x,y)|$$

Figure 13 below shows the performance measure of the different restoration algorithms. This algorithm clearly shows the relative performance of the various algorithms applied. The numerical comparison is given in Table II. For this contrast gain is used as a metric measure.

TABLE II: COMPARING CONTRAST GAIN VALUES

Restoration Methods	**Contrast Gain**
CLAHE	0.1106
Unsharp Masking	0.0865
Histogram Equalization	0.0610
Retinex Algorithm	0.1468
Atmospheric Transfer Function	0.1738

Figure 13: L-R: (a) Captured Color Scene corrupted by environmental distortion (b) Grayscale of (a), used for processing (c) CLAHE (d) Unsharp masking (e) Histogram equalization (f) Retinex algorithm (g) Atmospheric transfer function

V. CONCLUSION

Providing clear vision for driving in bad weather condition is a very challenging task. To solve this problem consistently and reliably across all weather condition requires proper understanding and application of various tools from radiometry & atmospheric-optics to image processing. It is further argued that the existing models using atmospheric optics alone are not suitable to encapsulate the underlying process responsible for such degradation. It is therefore essential to look into this problem from a new perspective where this research may provide essential understanding on the process for developing an advanced all weather vision tool for assisting driving personnel in poor lightning and bad weather conditions. This paper, therefore presents a new physics-based model in form of transfer function for predicting the environmental degradation to the captured image, as light travels from a source to an observer. This model can essentially compute the variations in environmental irradiance and airlight model used for study of atmospheric scattering and encapsulate it as a transfer function. This approach is found to be reasonably accurate and can be applied for various weather conditions including fog, haze, mist and rain while providing superior performance compared to only vision based or atmospheric optics based approaches.

VI. SCOPE OF FUTURE WORK

Work is in progress to apply the mathematical model described here in outdoor environment with necessary modification of the software and hardware. This also requires collection of ground truth data of the selected test sites.

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