iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VI **Month of publication:** June 2021

DOI: https://doi.org/10.22214/ijraset.2021.34984

Haze Removal System using Dark Channel Prior

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Abstract: Mostly in winter season, the Northern area of India is mostly affected due to heavy haze. The road traffic and air traffic is affected due to poor visibility. According to the survey of Ministry of Road Transport and Highways of India, the number of accident due to poor visibility increasing every year. Hence there is need of robust algorithm to enhance the visibility of the camera feed. In the proposed approach, image dehazing algorithm has been present using dark channel prior. The proposed algorithm is developed for outdoor images. The proposed system processed the image through dark channel prior, estimation of atmospheric light, estimation of transmission and scene radiance. The proposed system achieved the promising results on O-Haze dataset.
Keywords: Atmospheric light, Dark channel prior, Haze removal, Scene radiance, Transmission estimation

I. INTRODUCTION

The visibility of the outdoor image is caused by the absorption and scattering by the particles like haze, dust, fog etc. These factors are nothing but haze which affects the images. such images are reduced in quality and which in turn reduces contrast and visibility. The degraded images have low color contrast and fidelity. So, to remove these factors in-depth knowledge of the scene is required. The proposed algorithm for haze removal makes use of dark channel prior. De-hazing is done to restore the quality of the image. Thus, simple haze removal system is of effective use to get haze-free images.

In this approach, some steps are performed to remove haze. The haze removal algorithm takes in a single image as input. It is observed that the local region where natural light does not reach, the low intensity pixels called dark pixels were observed. It is calculated by the dark channel prior method. Likewise, the high intensity pixels are calculated using atmospheric light estimation. Using the dark channel and atmospheric light, the transmission of the hazy image is calculated and finally the scene radiance is achieved by adjusting the value of alpha [1].

This paper is organized as; In section II, the survey of recent approached for haze removal system has been explained in detail with their research gap. In section III, block diagram of the proposed system with detailed explanation is given. The implementation of the system with software details is presented in section IV, Results of the proposed haze removal system is explained in section V using qualitative and quantitative analysis. Finally, the proposed system is concluded in Conclusion section.

II. LITERATURE SURVEY

The previous study of algorithms and methods of haze removal has been described.

Z. Li et.al [2] first introduced a weighted guided image filter by combination of weighted guided filter and edge aware weighting with their advantages. They use weighted guided image filter inherits the advantages of the local as well as local smoothing filter like guided image filter [1][3]. The results of the system show better visual quality, but halo artifacts were avoided in the resultant image.

Y. H. Lai et.al [4] presents the method for haze removal system by estimating the optimal transmission map from the haze model. [4, 5]. In this method the optimal dark channel of hazy image is calculated to remove haze from the image. Then they combined two scene priors i.e. locally consistent scene radiance and scene radiance calculated by constrained minimization problem. Result is obtained by global optimality results and accuracy of fine-grained depth boundaries map [4].

Vaibhav Khandelwal et. al [6] presented a method for defogging technique and dark channel prioritization. Combining dark channels prior to the degraded image model, haze elimination from a single image becomes more effective and even simpler. Their method merely depends on the haze imaging model.

Zhong Chen et. al [7] elaborates the principal of image defogging method using atmospheric transfer function and dark channel prior. Firstly, the brightness, transmittance of the hazy image is acquired then transmittance is optimized by guided filter [7]. This algorithm can most effectively identify the specific location of an object and restore the image detail to enhance the image from fogging effect.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI Jun 2021- Available at www.ijraset.com

III. PROPOSED SYSTEM

The block diagram of the proposed system is shown in Fig.1. Each block of the block diagram is as explain below in detail.

A. Database

The systems are not objective or straightforward when ground truth of the image of the datasets are not available. Hence, we select O-Haze dataset. The dataset contains 30 images of outdoor hazy images with respective haze free (ground truth) images. This database is prepared using real haze produced by the advance, professional haze machine. The images were collected in controlled environment to ease of color calibration. The haze and ground truth images were collected in same illumination conditions. The advantage of this dataset is that allows to compare the previous image dehazing techniques using traditional image quality metrics.

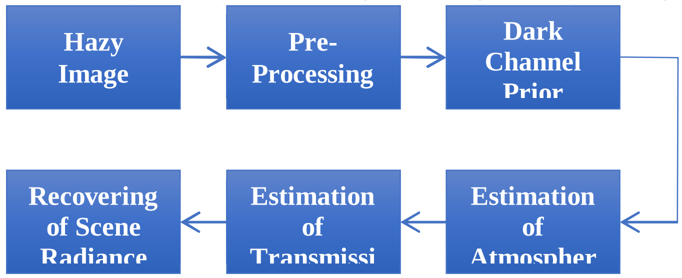

Figure 1. Block diagram of proposed haze removal system

B. Pre-processing

The raw input images are fade up with the noises. In this approach, the median filter is used to remove salt and pepper noise. The median filter smoothens the image. First R, G, B channel [9] is separated and the median filter of mask 3x3 or 5x5 or 7x7 is applied over each channel. Then categorize all the pixel values from the neighborhood surrounding into numerical order and consider each pixel in the image in turn and look at its neighbor value to decide whether it is a delegate of its atmosphere. Then find out the middle element of the mask. The median is calculated by first organizing all the pixel values being considered with the middle pixel value [9].

Let consider an image, the mask of 3 x 3 is applied over the image as shown in brown color in Fig.2. Neighborhood values of middle element 150 are 124, 126, 127, 125, 123, 119, 115, and 120 and its median value is calculated as by arranging the neighborhood value in ascending or descending order as shown below and pick the middle value from the array.

115, 119, 120,123, 124, 125, 126, 127, 200

123	125	126	130	140
122	124	126	127	135
118	120	200	125	134
119	115	119	123	133
111	116	110	120	130

(a)

123	125	126	130	140
122	124	126	127	135
118	120	124	125	134
119	115	119	123	133
111	116	110	120	130

(b)

Figure 2. Example of median filter (a) Input image (b) Output Image

The middle element of the mask is replaced with the middle element of sorted array. The resultant image is as shown in Fig. 2(b). The median filter removes the salt and pepper noise from an image and smoothen the image.

C. Dark Channel Prior

It is observed that the local region where natural light does not reach, the low intensity pixels called dark pixels except sky region were observed. The dark pixels are in an image is observed in following region.

1) Shadows.
2) Colorful objects or surfaces.
3) Dark objects or surfaces.

Roughly, dark channel estimation is the roughly estimation of depth on an image.

D. Atmospheric Light Estimation

The atmosphere consists of dust or micro particles on clear days [9]. In real images, the brightest pixel could be on a white car or a white building. Brightest pixel has the highest intensity and to calculate the highest intensity need to calculate atmospheric light. Use the dark channel prior algorithm to improve the atmospheric light estimation [1].

When the fog is thicker the value should be made bigger because of the heavy decline of the light transmission. Conversely, the value should be a little bit small. Practically we need to estimate atmospheric light value [10]. The general method to estimate the atmospheric light value is:

1) Pick the top 0.1% brightest pixels in the dark channel.
2) Among these pixels, the highest intensity in the input image I am selected as the global atmospheric light intensity [10].
3) This is the simple method based on a dark channel prior to calculating the atmospheric light value [1].

E. Estimation of Transmission Light and Scene Radiance

The aim of Haze Removal is to recover J from I and so to find out atmospheric light and transmission light is needed [10]. The expression for the input image is represented as:

$$I(x) = t(x).J(x) + \big(1 - t(x)\big).A \tag{1}$$

Where,

I am the Intensity of the input image.
J the Intensity of recovery image
t is the Transmission.
A Global Atmospheric light

$$J^{dark}(x) = \min_{C \,€\, \{r,g,b\}} \left(minJ^{c}(x)\right) \tag{2}$$

J^C is a color channel of J. D^{ark} is the darkest pixel in the image. It has a low intensity. So, consider the darkest pixel as 0 initially,

$$J^{dark} = 0 \tag{3}$$

Putting equation (2) into (1)

$$\frac{I^c(x)}{A^c} = t(x).\frac{J^c(x)}{A^c} + (1 - t(x)) \tag{4}$$

Apply two minimum operators on both sides:

$$\min\left(min\frac{I^c(x)}{A^c}\right) = t(x).\min\left(min\frac{J^c(x)}{A^c}\right) + (1 - t(x)) \tag{5}$$

From equation (2):

$$\min\left(minJ^c(y)\right) = 0 \tag{6}$$

Putting (6) into (5) then we get the value of Transmission light:

$$t(x) = 1 - \min(min\frac{I^c(y)}{A}) \tag{7}$$

If the haze is completely removed, the image after processing will look unnatural due to a lack of depth of field. Therefore, when the light transmission is calculated, a weight coefficient is usually added. Through the weight coefficient, the image after processing can reserve a very small amount of haze. Finally, the light transmission is:

$$t(x) = 1 - \omega.\min(min\frac{I^c(y)}{A^c}) \tag{8}$$

When fog is thicker need to estimate Atmospheric light. Pick the top 0.1 percent brightest pixels in the dark channel. The highest intensity in the input image I is selected as the global atmospheric light intensity. Haze removal image can be:

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

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IV. IMPLEMENTATION

A. *Software platforms*

The brief introduction of software platform is given in this section.

1) *PyCharm:* PyCharm is an Integrated Development Environment (IDE) used in computer programming, especially for Python language. Implementation of digit and Marathi sign language recognition is carried out using OpenCV and Python on Intel core TM i5 Processor. For the programming part, on OpenCV, we need to install an extra three important libraries.
2) *Image Processing:* OpenCV 3.7: Open source Computer Vision (OpenCV) is an image processing and computer vision library mainly developed for artificial vision. It has a BSD license (free for commercial or research use). OpenCV was originally written in C but currently, it's a whole C++ interface and there's additionally a full Python interface to the library. Open source computer Vision Library, also called OpenCV, is associated in a freeware software package that is aimed toward computer vision. It is used in this project because of its versatility as well as the fact that it has a C++ interface. OpenCV runs on most of the major Operating Systems (OS), which makes it useful when using another computer to program or test.
3) *Language: Python:* Python is a high-level programming language used for programming. Python, an interpreted language, supports several programming scripts and a syntax that allows you to use programs in most languages such as C ++ or Java. The language provides constructions designed to permit clear programs at each scale. Python is easy and simple to know, the python code is way easier than alternative languages.

B. *Flow Chart*

Flow chart of the proposed system is as shown in Fig. 3.

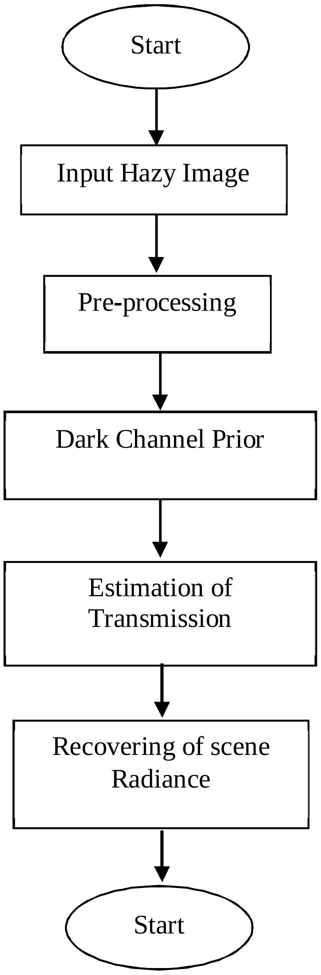

Figure 3. Flow chart of the proposed system

V. RESULTS

The analysis of the proposed system is evaluated using qualitative and quantitative analysis.

A. *Qualitative Analysis*

The results of the proposed system are evaluated on O-Haze dataset. The results on some of the images of O-Haze dataset are shown in Fig. 4. Result of each steps are shown below.

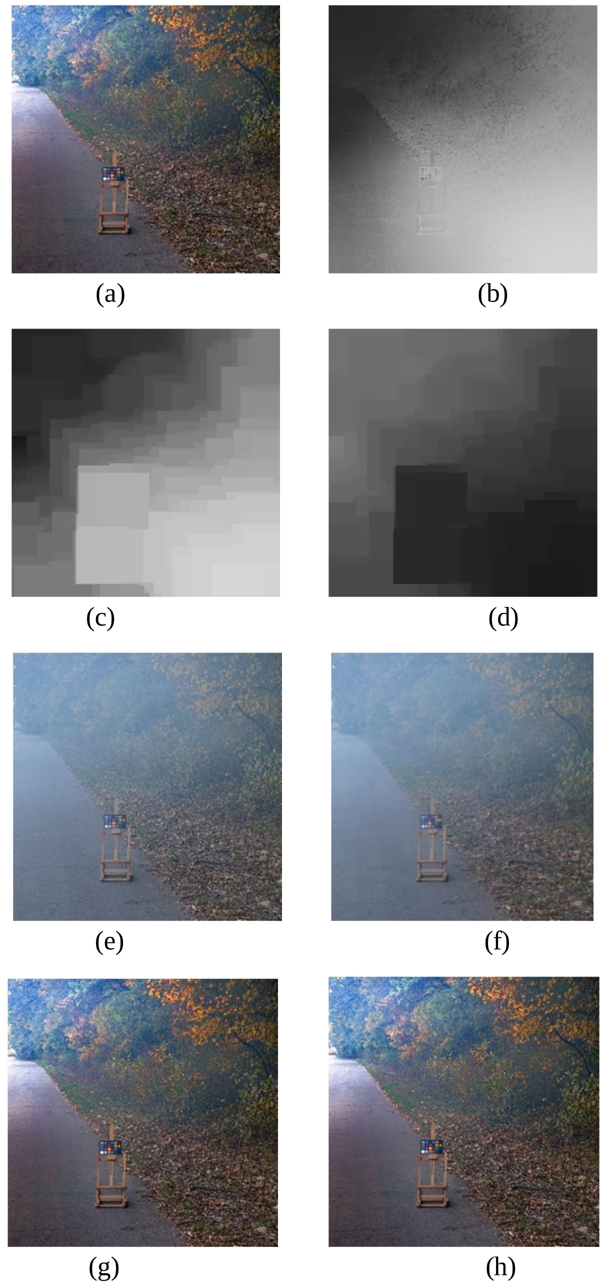

Figure 4. Qualitative analysis of the proposed system (a)Input Image (b)Dark channel Image (c)Transmission estimation image (d) Transmission refinement (e) Scene recovery image with transmission estimation (f) Scene recovery image with transmission refinement (g) Ground truth Image (h) Output of proposed system

From the qualitative analysis, it is observed that the output image and ground truth image is visually same and the proposed system able to remove the large amount of haze from the image.

B. Quantitative analysis

The qualitative analysis of this system performed using Mean Square Error (MSE), Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR), and Structural Similarity Index Matrix (SSIM).

1) *Mean Square Error (MSE):* MSE stands for Mean Squared Error and it is calculated by the comparison of the ground truth haze free image and output of proposed system. It is given by

$$MSE = \frac{1}{[N\times M]^2}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(X_{ij}-Y_{ij}\right)^2 \qquad (1)$$

Where $N \times M$is the numbers pixels in the image, X_{ij} is the vector of observed value and Y_{ij} is the vector of the predicted value.

The MSE is the mean $\left(\frac{1}{[N\times M]^2}\sum_{i=1}^{N}\quad\right)$ of the squares of the errors $\left(X_{ij}-Y_{ij}\right)^2$. This is a computable quantity for a particular sample hence it is sample dependant.

2) *PSNR:* PSNR is the parameter of the video file that means Peak Signal to Noise Ratio. PSNR and MSE both are inversely proportional to each other and PSNR can be measured by the following equation.

$$PSNR = 10\log_{10}\left[\frac{I^2}{MSE}\right] \qquad (2)$$

Where I is the maximum possible value of audio.

3) *RMSE:* RMSE is a parameter that means Root Means Square Error which is calculated as the square root of MSE value.

$$RMSE = \sqrt{\frac{1}{[N\times M]^2}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(X_{ij}-Y_{ij}\right)^2} \qquad (3)$$

4) *SSIM:* SSIM is the measure of the quality degradation caused by the modification and loss in the data transmission. The SSIM is calculated in this approach is between the ground truth haze free image and output of proposed system.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y+C_1)(2\sigma_{xy}C+_2)}{(\mu_x+\mu_y+C_1)(\sigma_x+\sigma_y+C_2)} \qquad (4)$$

where μ_x, μ_y, are the local mean, σ_x, σ_y are the standard deviation and σ_{xy} is the cross-covariance for data x, y.

The mean, standard deviation, and cross variance is given by

$$\mu_x = \frac{1}{N}\sum_{i=1}^{N}x_i \qquad (5)$$

$$\sigma_x = \left(\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\mu_x)^2\right)^{\frac{1}{2}} \qquad (6)$$

$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\mu_x)(y_i-\mu_y) \qquad (7)$$

Table. I Quantitative Analysis

Image Name	MSE	RMSE	PSNR	SSIM
01_outdoor_hazy	106.91	10.33	16.4	0.80
02_outdoor_hazy	93.39	9.66	17.36	0.75
03_outdoor_hazy	88.76	9.42	17.26	0.84
04_outdoor_hazy	102.41	10.11	5.46	0.42
05_outdoor_hazy	107.02	10.34	6.37	0.46
06_outdoor_hazy	92.19	9.60	18.95	0.72
07_outdoor_hazy	95.92	9.79	18.55	0.82
08_outdoor_hazy	92.68	9.62	15.93	0.49
09_outdoor_hazy	102.69	10.13	10.13	0.45
10_outdoor_hazy	80.24	8.95	13.92	0.77
11_outdoor_hazy	107.21	10.35	16.14	0.56
12_outdoor_hazy	88.52	9.40	20.38	0.83

13_outdoor_hazy	104.34	10.21	5.36	0.42
14_outdoor_hazy	97.05	9.85	19.18	0.78
15_outdoor_hazy	100.63	10.03	8.90	0.56
16_outdoor_hazy	104.17	10.20	15.81	0.47
17_outdoor_hazy	107.82	10.38	12.68	0.63
18_outdoor_hazy	82.35	9.07	19.50	0.72
19_outdoor_hazy	91.10	9.54	9.03	0.64
20_outdoor_hazy	99.01	9.95	10.40	0.58
21_outdoor_hazy	95.38	9.76	20.65	0.68
22_outdoor_hazy	63.67	7.97	27.72	0.91
23_outdoor_hazy	75.07	8.66	19.11	0.90
24_outdoor_hazy	96.62	9.82	11.78	0.73
25_outdoor_hazy	90.59	9.51	19.19	0.63
26_outdoor_hazy	106.62	10.32	16.05	0.64
27_outdoor_hazy	105.45	10.26	9.81	0.64
28_outdoor_hazy	100.98	10.04	18.69	0.67
29_outdoor_hazy	99.74	9.98	11.58	0.59
30_outdoor_hazy	108.53	10.41	18.27	0.77
31_outdoor_hazy	89.48	9.45	20.13	0.86
32_outdoor_hazy	93.12	9.65	19.45	0.82
33_outdoor_hazy	109.63	10.47	8.88	0.62
34_outdoor_hazy	99.85	9.99	4.60	0.25
35_outdoor_hazy	100.66	10.03	5.63	0.44
36_outdoor_hazy	95.46	9.77	11.16	0.75
37_outdoor_hazy	101.16	10.05	7.24	0.48
38_outdoor_hazy	107.66	10.37	4.15	0.28
39_outdoor_hazy	100.17	10.00	18.90	0.69
40_outdoor_hazy	101.60	10.07	18.41	0.83
41_outdoor_hazy	100.16	10.00	20.19	0.85
42_outdoor_hazy	90.56	9.51	15.33	0.73
43_outdoor_hazy	98.83	9.94	12.92	0.79
44_outdoor_hazy	99.33	9.96	19.39	0.84
45_outdoor_hazy	89.61	9.46	21.23	0.68

The graphical analysis of the proposed system is shown below.

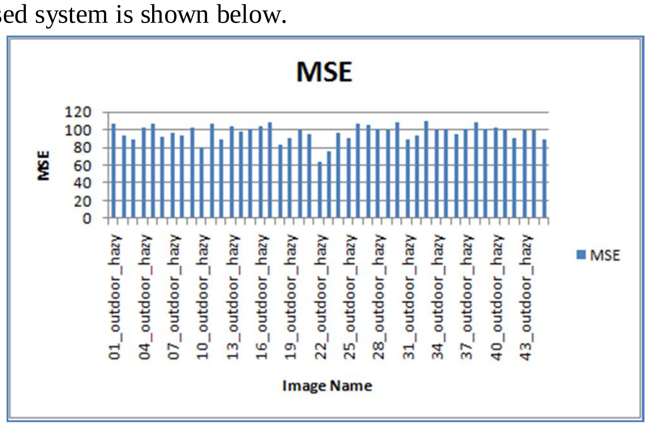

Figure 5. Performance Analysis using MSE

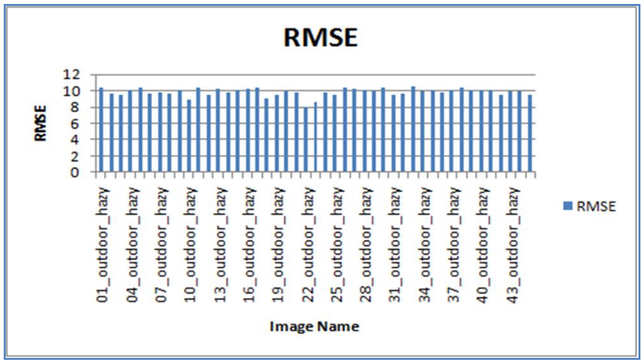

Figure 6. Performance Analysis using RMSE

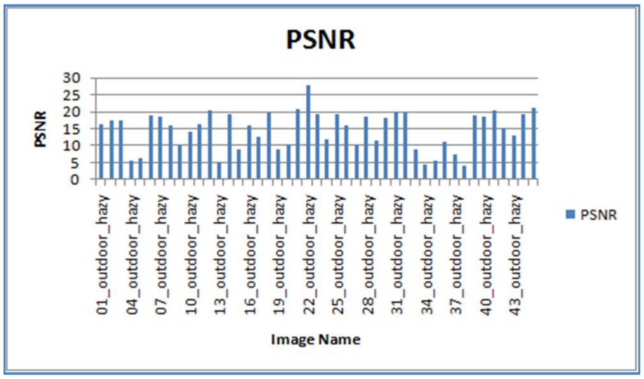

Figure 7. Performance Analysis using PSNR

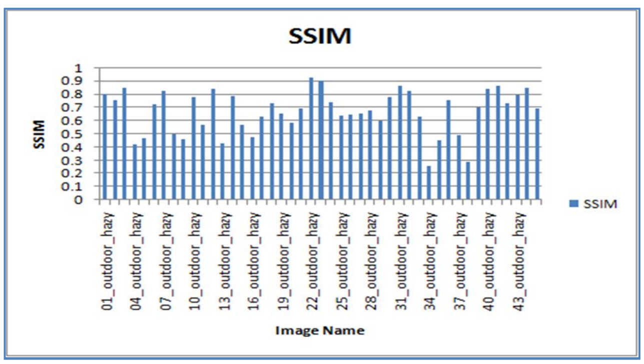

Figure 8. Performance Analysis using SSIM

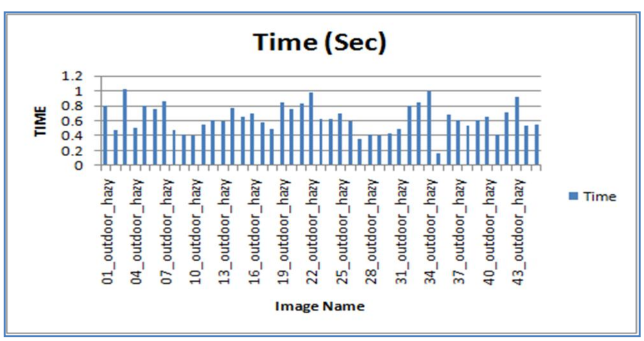

Figure 9. Performance Analysis using Time

From the quantitative analysis of the proposed system, it is observed that the PSNR and SSIM value for proposed system is promising.

VI. CONCLUSION

In this approach, the simple, effective, and powerful haze removal for single image using dark channel prior has been presented. The outdoor hazy image from the O-Haze dataset are used for this approach. The hazy images were processed by dark channel estimation. Then, the atmospheric light is calculated by estimating the brightest pixel in an image. Then the transmission map is created to get the depth information of the haze and finally, the scene radiance is recovered. The performance of this system is evaluated using MSE. RMSE, PSNR and SSIM on O-Haze dataset. The qualitative analysis of this system shows that the visibility of the images improved impressively while the quantitative analysis shows that the PSNR of the maximum image samples of the O-Haze dataset observed to be maximum with minimum MSE. The MSE of the image where the object color is like the atmospheric light is found to be maximum. Hence the improvement in the MSE value for such an image will be the future direction of this research. The selection of omega factor is also a crucial step. In this haze removal system, the omega factor must tune manually according to the depth of haze. In future, the omega value can be calculated by extracting the features from the hazy image and machine learning algorithm. Also, the PSNR of the system can be improved by using advanced deep learning techniques like Generative Adversarial Network (GAN).

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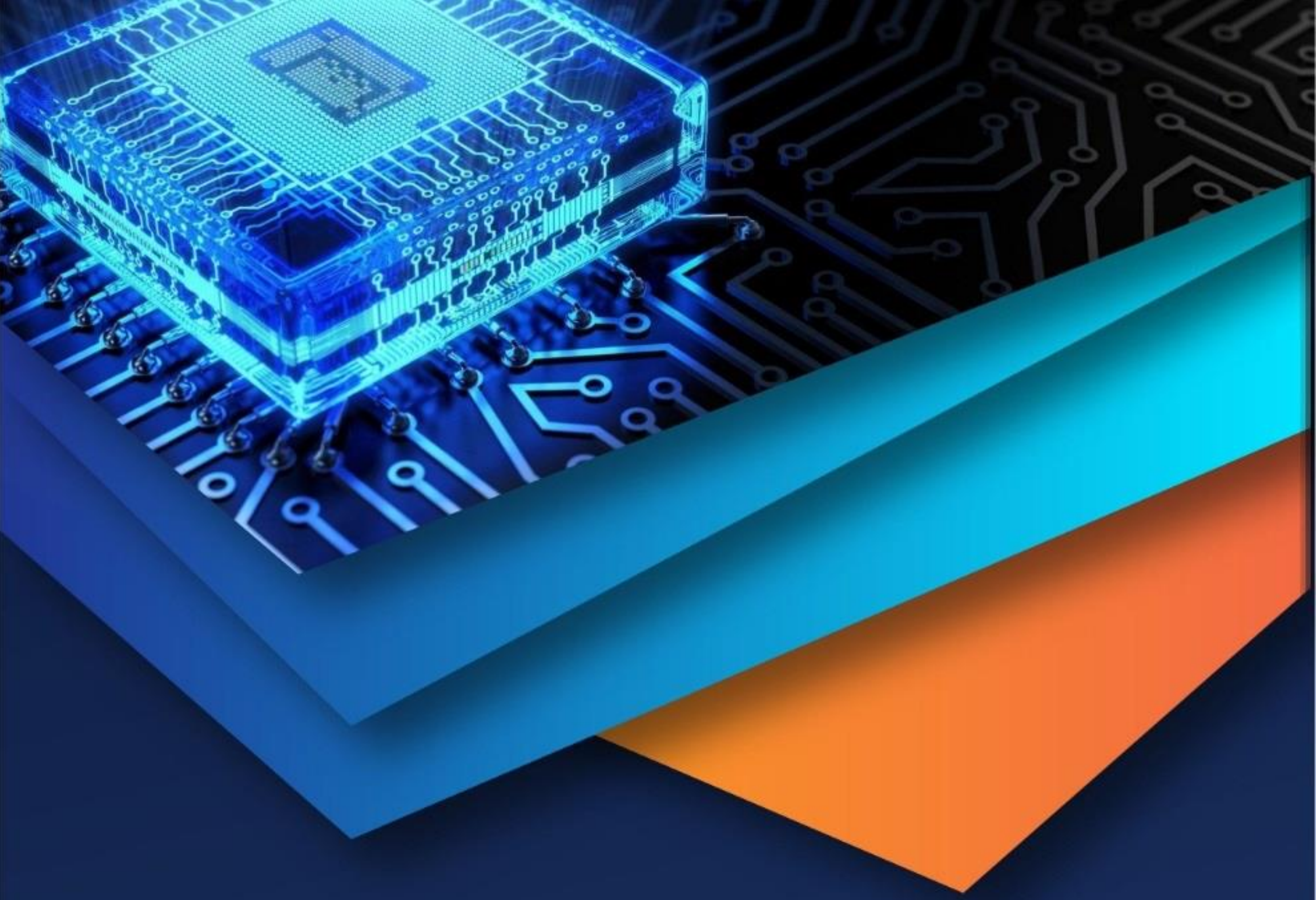

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