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ADAPTIVE HYBRID IMAGE DEFOGGING FOR ENHANCING FOGGY IMAGES

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Abstract

Images and video captured using camera systems can be seriously degraded by the effect of weather conditions such as fog and haze. Image restoration of true scenes from foggy weather conditions can make a significant difference in many computer vision algorithms such as tracking, surveillance and detection. The main aim of this paper is to develop an Adaptive Hybrid Image Defogging (AHID) algorithm that helps in image restoration with better quality for defogging images under high foggy environments. Combined restoration algorithm consists of image enhancement techniques and multi-level fusion-based defogging algorithms. The adaptive hybrid algorithm consists of many image enhancement techniques with a Dark Channel Prior (DCP) Algorithm to estimate the amount of fog present in the images and atmospheric light as well. The fusion-based defogging algorithm will reduce the remaining artefacts present in the hazy image model. Experiments were conducted with various climatic conditions and the results are summarized in the paper.

Keywords: Adaptive hybrid image defogging algorithm, Algorithm, Computer vision, DCP fog, Image restoration.

1. Introduction

The small amounts of water droplets present in the atmosphere and when sunlight hits on it could scatter the light and a white layer formed in the atmosphere, which is called fog. Presence of fog has become so common in current day scenario. Fog is caused due to pollution and climatic conditions. Identifying objects and person in a foggy scenario is very difficult. A poor visibility condition also creates hazards during flight landing in runways. Vehicle traffic is also affected due to the poor visibility of roads. The headlights used does not give a clear picture of the scene. Fog is also considered as a major reason for accidents in land and water as well. In satellite images and military application, the fog or smoke occludes the scene behind.

Fog removal techniques are required here for better visualization. Defogging algorithms are highly useful in such cases. In this paper, the fog removal is considered as an image enhancement problem and an adaptive hybrid image-defogging algorithm is suggested to visualize objects in a foggy image. The above algorithm performs better than the existing techniques and could be useful for real-time automated driving systems, surveillance, etc.

In addition to that, the algorithm can be applied for different computer vision applications such as tracking and visual restoration of photographs [1, 2]. Image Restoration is considered as an important task in many computer vision algorithms. Image noise could occur due to many reasons in visual applications; therefore, denoising is done on images to get a clear output. Filtering techniques such as linear filtering and order statistical filtering are used for this purpose based on the nature of noise affected [3] and the application used [1, 4].

Based on studies by Yu et al. [5] and Ding and Tong [6], foggy images are similar to noisy images, however, the difference is that the fog will be continuous in nature and hence, above-mentioned filters cannot be used to get enhanced output. The fog present in an image may not be uniform at all locations. Hence, there are chances that some part of the images may be visible and some part may not be visible. Identifying the foggy region and enhancing that region is required to get a better output. This requires an adaptive defogging algorithm. The foggy regions in an image will create problems in feature extraction and detection of objects.

Many such defogging algorithms are mainly based on the outdoor scene formulation, atmospheric light estimation models. Narasimhan et al. analysed different image degradation conditions such as fog, haze, smoke and cloud. Based on these factors a hazy model has been formulated in his paper [6, 7].

This model uses the information present in the non-foggy area and assumes a mild presence of fog. He et al. [8] tried to enhance by considering luminance, chrominance and saliency weight maps and fuses images at multi-scale to get the result. The foggy region and non-foggy region has to be treated separately to give a better result. Hence, in this paper, an adaptive hybrid image-defogging algorithm is used to enhance these regions separately and fusion at multi-scale is done to improve the overall performance and establish an enhanced haze-free model.

The paper is organized with Section 2 on related works, Section 3 on proposed work, Section 4 on result analysis and Section 5 with a conclusion.

2. Related Works

This section includes various techniques for defogging images including dark channel algorithm and various fusion techniques used in similar applications.

2.1. Dark channel prior algorithm

A hazy image model is formulated and analysed with different atmospheric models and estimated the atmospheric light and transmission light to obtain the haze-free output. In an image, the hazy regions are identified as lighter patches and the non-hazy regions are identified as dark patches with colourful information. Based on this method by Arora et al. [9] and Narasimhan and Nayar [10], the DCP algorithm has been developed. For a haze-free image, the dark channel tends to zero. The air-light can be estimated by the deepest haze using dark channel prior algorithm.

2.2. Improved dark channel prior algorithm

Improved DCP algorithm is the same as that of the discussed above with an addition of gamma correction. The value of gamma decides the brightness of the resultant output. Gamma correction is done at the end of the DCP algorithm [11, 12]. When the image is fully covered with fog, DCP algorithm fails to retrieve the image. It also creates false colour artefacts. DCP algorithm helps the user to find the regions were haze is present and allows preserving the other regions that were not degraded by fog [10].

2.3. Dehazing using multi-scale fusion technique

For an input image, white balancing and contrast enhancement are performed separately. On each of the outputs luminance, chrominance and saliency weight maps are calculated [9, 13]. The images are then fused together to get the resultant output.

2.3.1. Luminance weight map

The luminance weight map is calculated as given in Eq. (1). The luminance weight map acts as an identifier for the degradation induced on the particular input and it is used to distinguish the amount of haze present in the image.

$$W_L^k = \sqrt{1/3\left[\left(\mathrm{R}^k - L^k\right)^2 + \left(\mathrm{G}^k - L^k\right)^2 + \left(\mathrm{B}^k - L^k\right)^2\right]} \tag{1}$$

The W_L is the weight map and the L value is luminance value, which is the average of RGB channels in an image.

2.3.2. Chrominance weight map

The chromatic weight map calculates the saturation control from these weight maps by transforming from RGB to HSV colour space. The S-value as given in Eq. (2) with $S_{max} = 1$ and $\sigma = 0.3$ values chosen based on a central limit theorem to comprise almost all information in that image. The maximum value is chosen because to identify and removing fog because high value represents heavy fog.

$$W_C^K(x) = \exp\left(-\frac{\left(S^{k(x)} - S_{\max}^k\right)^2}{2 * \sigma^2}\right) \tag{2}$$

2.3.3. Saliency weight map

The weight map helps to identify the degree of conspicuousness and the perceptual quality used when a person looks at certain objects that stand out on those images. Gaussian pyramids are calculated for the weight maps of the two input images [4, 8]. Laplacian pyramid is calculated for the input images. A multi-level fusion of these Gaussian and Laplacian pyramids is done to get the reconstructed output [9, 13, 14].

3. Proposed System

Multi-scale fusion technique performs poorly when the image is completely covered by fog. Some amount of fog will present in the output image as well. DCP algorithm enhances the lighter and darker channels. Adaptive Hybrid Image Defogging (AHID) algorithm proposed in this paper uses the multi-level fusion of weight maps after enhancing the lighter and darker channels separately. This algorithm enhances the details of an image in an improved manner as compared to the methods discussed above. The architecture diagram of the proposed system is given in Fig. 1.

Input image for the algorithm is the foggy degraded image, which is enhanced using gamma correction, brightness enhancement and Contrast Limited Adaptive Histogram Equalization (CLAHE) The lighter and darker regions are enhanced using DCP algorithm that is followed by multi-scale fusion based on weight maps. The edges of the result are enhanced using unsharp masking and give as output. The details of each block are discussed in detail as follows:

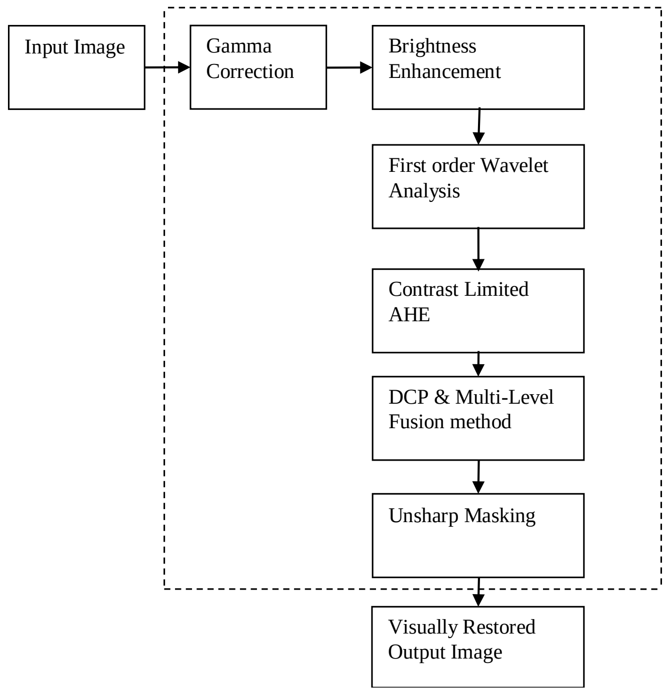

Fig. 1. Proposed AHID system

3.1. Gamma correction

Gamma correction can be used to enhance a fully whitened image so as to reduce the amount of light by choosing the gamma value between 0 to 1 as given in Eq. (3) [1, 4, 15].

$$V_{out} = AV_{in}^{\gamma} \tag{3}$$

A is the magnitude value and V_{in} is the input hazy image.

3.2. Brightness enhancement

A linear brightness enhancement is done to avoid the loss of dark information from the images as given in Eq. (4). This preserves the details of the image and prevents artefacts from being formed.

$$f(x) = \alpha V_{out} + \beta \tag{4}$$

The V_{out} is the output image and β value is the brightness constant. For increased brightness, a positive constant should be given to β [3, 16].

3.3. First-order wavelet analysis

Here wavelet analysis has been used for obtaining the most relevant information after the preprocessing operations. Hence, the wavelet analysis acts here as a low pass filter, which helps to get the most approximated results from the processed image and hence, it can be further used to get more relevant results.

Here this system uses Daubechies wavelet for the first order and the low values are chosen as we are not interested in the sharp region of noise and hence, most of the noises are removed by using wavelets [5, 6, 9].

3.4. Contrast limited adaptive histogram equalization

Adaptive histogram equalization method is used in order to have an enhancement irrespective of the lower and higher values and the whole image is enhanced and hence, the details will not get lost. However, the problem is that there are chances of noise embedded on those images in order to avoid the noise; the system needs to limit the contrast on those images as given in the Eq. (5).

$$h(v) = round\left(\frac{CDF(v) - CDF_{\min}}{(M*N) - 1}\right)(L-1) \tag{5}$$

The $h(v)$ is the output values of an image and $CDF(v)$ is cumulative distributive function and the CDF_{min} is also chosen here and M and N are row size and column size respectively. $CDF(v)$ is obtained by using Eq. (6).

$$CDF_x(i) = \sum_{j=0}^{i} p_x(j) \tag{6}$$

where, $p_x(j)$ is the probability of a number of occurrences of each value in an image and the $h(v)$ is substituted with each of the values in an image and the image gets enhanced [16-18].

Contrast can be limited by using the clipping method and the clipping is performed by applying different steps on those images. CLAHE is performed by choosing a particular block size, the histogram is calculated each time, and the adaptive histogram equalization is performed with a clipping factor.

The contrast gets limited by using the above CLAHE method and because of that, we get a better resultant output [3, 10, 19, 20]. These algorithms discussed below help to get results that are more relevant.

3.5. DCP and multi-level fusion method

Dark Channel Prior method and Multi-level fusion methods are discussed earlier and hence, none of the systems combined these algorithms [4, 9].

The DCP algorithm is most important in terms of finding the hazy and non-hazy regions by using patches [13, 17, 20]. From that, we could able to get a haze-free image by using the formulation given in Eq. (7).

$$I(x) = u(x)t(x) + A_{ir}(1 - t(x)) \tag{7}$$

The $U(x)$ is the haze-free image model and $t(x)$ is the transmission coefficient were A_{ir} is the air-light, which is the main degradation function for each image.

Therefore, retrieving $u(x)$ from the equation helps to get a haze-free image model.

The transmission is also calculated as given in Eq. (8).

$$t(x) = 1 - w\left(\min_{patches}\left(\min_{(R,G,B)}\left(\frac{I_C}{A_{ir}}\right)\right)\right) \tag{8}$$

Here the w value lies between 0 to 1 and depending on the amount of haze required in the enhanced image. The transmission and atmospheric air light are calculated to get an enhanced output as given in Eq. (9).

$$u(x) = \frac{I(x)\text{-}A_{ir}}{\max((t(x), t_0\ )} + A_{ir} \tag{9}$$

The t_0 value is typically assigned as 0.1 and the enhanced output is retrieved in the form of a haze-free image. Hence, we also discussed that the major disadvantage that we cannot able to retrieve information from image densely covered with fog [13, 14, 20]. Dehazing using multi-level fusion is discussed as follows.

As shown in Fig. 2, multi-level fusion has been done on the output of the DCP algorithm and it is divided into 2 parts [3]. On the first part, white balance is performed and on the other hand, contrast enhancement is done.

Calculate the chrominance, luminance and saliency weight maps and obtain a resultant output. Xu et al. [3] proposed to use Gaussian pyramids on the resultant weight mapped image and laplacian pyramid on the white balance, contrast enhancement inputs.

Fuse both pyramids to get a reconstructed output, the level of pyramids are also chosen as 5.

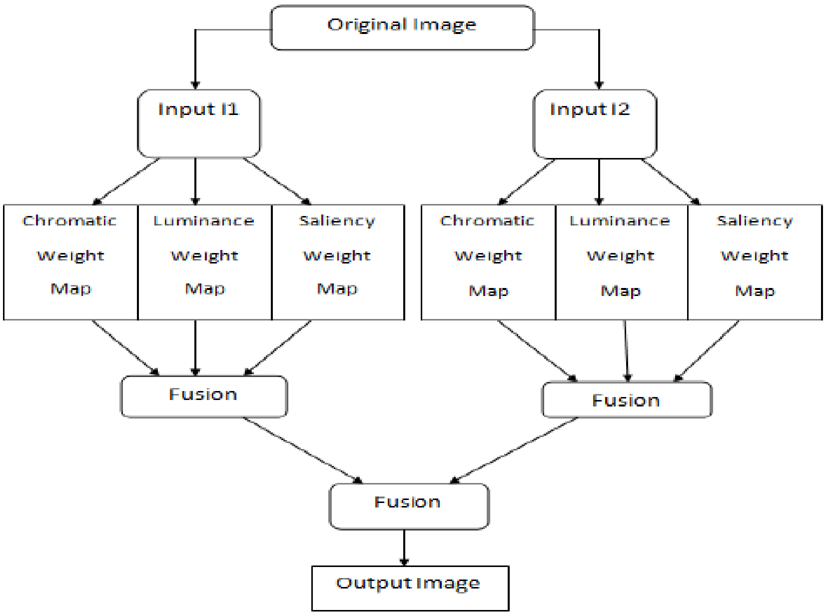

Fig. 2. Multi-level fusion method.

3.6. Unsharp masking

Apply a Gaussian filter on the resultant output image to get a filtered result by using a specific sigma value and it absolutely depends on the desired output [3, 6, 15]. Subtract the original image and filtered image to get the edges of the previously enhanced image. Add the edges with the enhanced original image to get a better output and hence, we get a defogged image and most of the information will be visible after the step and we get a visually restored output image after using our new derived algorithm.

4. Result Analysis

The proposed system is tested with different weather conditions and the results are summarized below along with the dataset specification.

4.1. Dataset specifications

The dataset consists of above-mentioned images on which, the proposed algorithm is tested.

- The standard dataset is chosen from the laboratory for image and video engineering under the University of Texas in Austin and generated by researchers.
- Images were taken under various climatic conditions with low and dense fog conditions. Images chosen are HD quality with a resolution of 300 dpi has been chosen for the analysis. Input images are represented with RGB colour representation.
- Images taken from a various distance are also considered for analysis to verify depth information.

4.2. Result analysis

The output of a dense fog image, Fig. 3(a) and light fog image, Fig. 3(c) is shown in Figs. 3(b) and (d) respectively.

Figure 3(a) shows the input image and major portion of the image is covered with dense fog and the information is not at all visible. The robustness of AHID method is proven in Fig. 3(b) as some persons are in the image and it is not visible as compared with the original image. In Fig. 3(b), nearer information is preserved and farther information is lost. The output of a light fog image, Fig. 3(c) consists of a rock with some people on it gives you a clear picture of AHID algorithm in Fig. 3(d).

Fig. 3. Comparison of visibility between input image and AHID method.

Figure 4 shows the intermediate results of the AHID method for the input image shown in Fig. 4(a). As discussed in Section 3, the intermediate results of the proposed method are given in Fig. 4(b) through Fig. 4(h). Fig. 4(b) shows the output of gamma correction, Fig. 4(c) with brightness enhancement followed by first-order wavelet analysis in Fig. 4(d). CLAHE enhanced image is given in Fig. 4(e). Figure 4(f) shows you the output of the DCP algorithm and the output of dehazing algorithm is given in Fig. 4(g). As you can see most of the foggy regions get recovered after all the process. Still some amount of fog present in the system and sharpening the edge will help in getting a restored output as demonstrated in Fig. 4(h).

Fig. 4. Intermediate results of AHID algorithm.

Figure 5 shows the comparison between the existing methods and the proposed method for an aerial and land view of a city and forest region in Figs. 5(a) and (f) respectively. In Figs. 5(b) and (g) gives the corresponding output of DCP as discussed in section 2.1. It could be observed that most of the region is very much dark and the details are not visible under this condition. Results of Improved DCP as discussed in Section 2.2 are given in Figs. 5(c) and (h). These results have better visibility and brightness when compared to that of DCP. The output of multi-level dehazing is given in Figs. 5(d) and (i). This method shows more details when compared to previous methods, however, the amount of fog removed is not complete and still, some regions of the image are hidden in the fog. The output of the proposed AHID method is shown in Figs. 5(e) and (j). It could be observed that more details are recovered and fog removal is better when compared to previous methods. The proposed techniques have an advantage of enhanced robustness in case of heavily degraded (foggy) images.

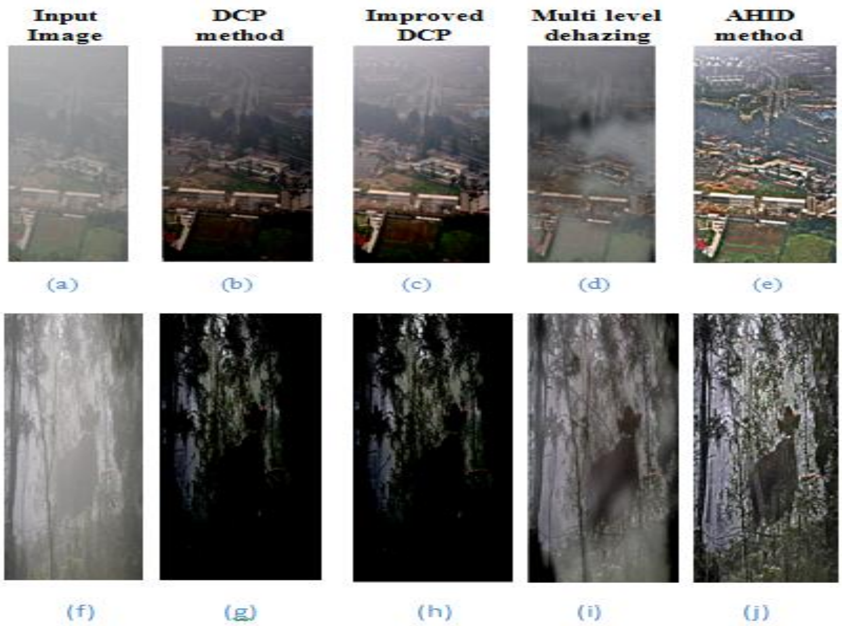

Fig. 5. Performance of various methods.

5. Conclusions

AHID uses the concept of gamma correction for enhancement, brightness enhancement for preventing degradation of quality. Over the image Dark Channel Prior method is applied for identifying regions with fog, which reduces noise and provides a haze-free image for processing in multi-level dehazing by using luminance, chrominance and saliency weight maps based features are used for the reconstruction of haze-free images.

Fog removal by AHID is efficient when compared to other methods as it extracts more details in foggy regions. When a dense fog image is considered, the objects that are nearby are clearly visible. The far off objects though introduces some colouring artefacts and blur could be clearly seen in the output.

Nomenclatures

A_{ir}	Atmospheric Air-light
B^k	Blue value in k^{th} index
$CDF(v)$	Cumulative Distribution Function at v^{th} position
$CDFf_{min}$	Minimum Cumulative distribution value
G^k	Green value in k^{th} index
$I(x)$	Hazy image
L^k	Luminance value in k^{th} index
M	Number of rows
N	Number of columns
$p(x)$	Probability of number of occurrence
R^k	Red value in k^{th} index
$t(x)$	Transmission constant
$u(x)$	Haze free Image
V_{in}	Input hazy image
V_{out}	Output hazy image
$W_C{}^k$	Chrominance weight map in k^{th} index
$W_L{}^k$	Luminance weight map in k^{th} index

Greek Symbols

α	Magnitude or scale values.
β	Amount of brightness to be added
γ	Gamma Value

Abbreviations

AHE	Adaptive Histogram Equalization
AHID	Adaptive Hybrid Image Defogging
CLAHE	Contrast Limited Adaptive Histogram Equalization
DCP	Dark Channel Prior

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