An Analysis of Dehazing Methods with Detail Fusion Combination Technique

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Abstract. The proposed Detail Fusion Combination Technique (DFC) has an objective to reduce the haze in a single image whilst preserving the image quality. The result of the proposed technique has been compared with other state-of-the-art dehazing approaches and evaluated with image quality assessment. Various image quality assessment methods such as the Mean Squared Error (MSE), Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) have been used to test the veracity of the result. Each resultant image has been evaluated with its corresponding ground truth counterpart respectively. Additionally, auxiliary datasets without ground truth images have been used with the proposed dehazing method in order to show the image quality qualitatively.

Keywords: image processing, dehazing method, ground truth, image quality assessment

1 Introduction

Images captured in the outdoor are affected by the presence of the atmospheric condition such as haze, fog, and smoke. These conditions cause low contrast and poor colour vividity in the distance. Haze is the most ubiquitous atmospheric phenomena where suspended participating particles in the air obscure the clarity of the sky and distant objects. Haze occurs naturally or anthropogenically such as an industrial pollutant, dust, and smoke. The effect of haze in the atmosphere is to degrade image quality captured due to light absorption and scattering.

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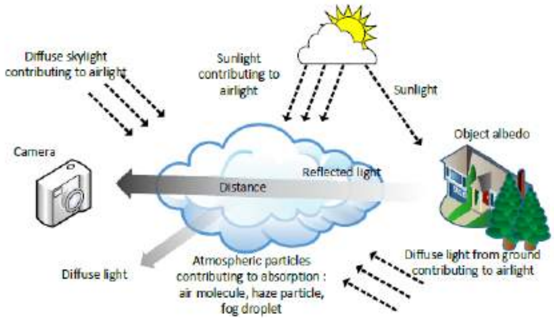

Fig. 1. Atmospheric scattering phenomenon

In computer graphics and computer vision, the model used to describe hazy or foggy image formation is the following equation [1].

$$I(x) = J(x)t(x) \; + \; A(1 - t(x)) \qquad (1)$$

where *I(x)* represent the haze affected the image, *J(x)* represents the haze-free image, *t(x)* represent as direct transmission and *A* as airlight.

The direct transmission formulated by a scattering coefficient, *β,* and distance, *d* between observer and object target, whilst *t(x)* represents a transmission map in with a scalar range of [0,1]. In the haze formation model, two mechanisms cause direct light attenuation, namely $J(x)t(x)$ and airlight $A(1 - t(x))$.

$$t(x) = e^{-\beta d(x)} \qquad (2)$$

Generally, when *t(x) = 0*, it means that the image is completely obscured by haze, where else *t(x)* =1 means that the image is completely clear and haze-free. For semi-transparent image, 0 < *t(x)* < 1. Consequently, the transmission map is shown as white when *t* = 1 and black when *t* = 0. This model has been widely used by previous researchers and applied in the image restoration process.

To obtain a haze-free image, there are four basic steps that must be implemented. The steps are as follows: airlight estimation, coarse transmission estimation, transmission refinement and the dehazing process itself. To reconstruct the haze-free image, the dehazing process inversed the model as follows:

$$J(x) = \frac{I(x) - A}{t(x)} + A \qquad (3)$$

The most challenging part of this process is to estimate the transmission map *t(x)* between the camera and the scene radiance. Using the wrong estimation value will produce an unappealing result for the image. Once the transmission has been estimated appropriately, then it simply proceeds to the dehazing process.

In early works, most of the dehazing approaches proposed their techniques and algorithm based on the atmospheric scattering model. He et al. [3] found that haze-free images of outdoor scenes or surfaces have at least one patch of very low-intensity value in one of the colour channel. They picked the top 0.1% the brightest pixels in the dark channel and categorised them as airlight. Finally, to have a smooth and robust estimation of *t(x)* that can avoid the halo effects due to the use of patches, the method employs the closed-form solution of matting.

Meng et al. [11] extend the idea of the dark channel prior when determining the initial values of transmission, *t(x)*, by introducing its lower bound. Zhu [4] proposes colour attenuation prior. Based on this prior, the scene depth of the hazy image is modelled as a linear model, where the unknown parameters can be estimated with a supervised learning method [4]. Cai et al. [5] proposed a learning-based framework that trains a regressor to predict the transmission value *t(x)* at each pixel from its surrounding patch. Berman [2] relies on the assumption that colours of a haze-free image are well approximated by a few hundred distinct colours, that form tight clusters in RGB space and pixels in a cluster are often non-local. In their algorithm, they first proposed a clustering method to group the pixels and each cluster becomes a haze-line. Then the maximum radius of each cluster is calculated and used to estimate the transmission. A final regulation step is performed to enforce the smoothness of the transmission map.

In this paper, we proposed a novel dehazing approach by combining two different dehazing techniques. Each technique is expected to yield different partial outcomes which will be used to reinforce each other results. Consequently, our proposed technique was designed to improve the existing dehazing result.

In Section 2, we discussed the detailed framework of each technique and the combination process. In Section 3, all the experiments and evaluation are presented and discussed.

2 Methodology

This paper proposed a new novel dehazing framework which combined two dehazing techniques, as follows:

- Enhanced detail & dehaze technique (DDE) [8]

- Fusion of enhanced dark channel prior and transmission map estimation techniques (FD) [7]

2.1 Enhancement of Detail and Dehaze (DDE)

The DDE technique computes new modified channels value based upon the modified dark channel prior and estimates the global atmospheric light by selecting the brightest pixel among the modified channels. The proposed modified channel prior assumed that most of the non-sky haze-free image will contain many dark pixels and bright pixels. Based on the modified channel prior, the modified channels are computed from the input haze degraded image using the following equation:

$$J^{modified} = \frac{max_c J^c + min_c J^c}{2} \quad (4)$$

The transmission will be estimated using the global atmospheric light and modified channels. After that, a dehazed image will be obtained by solving the atmospheric scattering model. An image can be decomposed into the base layer and detail layer.

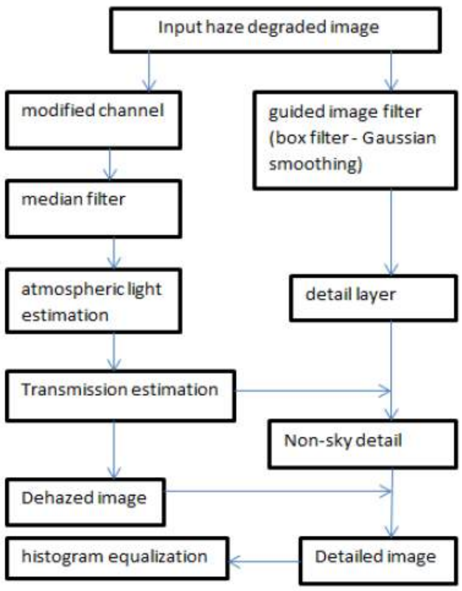

Fig. 2. The architecture of the DDE techniques

The DDE technique smoothes the input image with a guided image filter where the box filter is replaced by Gaussian smoothing. Subsequently, the detail layer is obtained by subtracting the smooth image from the input image. A non-sky detail layer is proposed as the combination of the detail layer and the transmission estimation. Subsequently, the non-sky detail layer will be recombined with the dehazed image based on the tone transform model. The recovered image is then post-processed based on the histogram equalization for the contrast enhancement [8].

2.2 Fusion of enhanced dark channel prior and transmission map estimation (FD)

This approach proposes enhanced techniques for dense haze effects restoration that degrade the scene of the static image. The first modifies dark channel prior to allow it to remove haze, which improves of contrast quality and obtains the haze intensity. The intensity of the dark channel allows estimation of the haze thickness value.

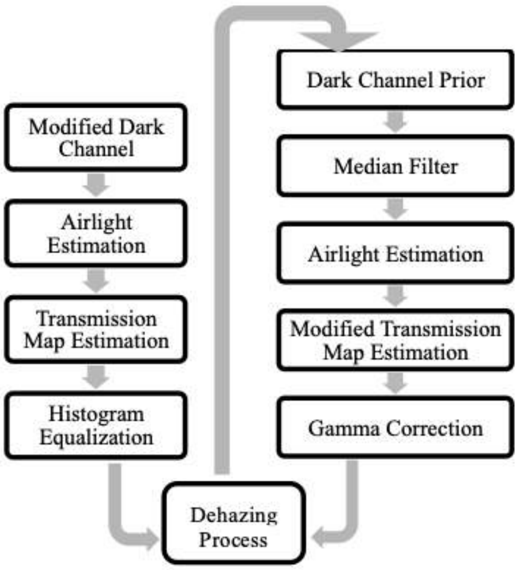

Fig. 3. The Architecture of A Fusion Enhancement

To find the intensity of the dark channel, a modified dark channel prior will be formed by taking the haze-free image part that generated from the original equation [4]. Based on the below equation, it will be squared to increase the effect of removing haze without deteriorating the image.

$$F^{DarkModified}(q) = min(max(F^c(p)))^2 \quad (5)$$

Then, transmission map estimation was modified to improve the image colour quality and its details. Derived from the original transmission map estimation (He, 2009), modify the equation by adding the square root.

$$t^{Modified}(p) = \sqrt{1 - w\left[min\left(min\left(\frac{H^c(p)}{A^c}\right)\right)\right]} \tag{6}$$

Besides that, the median filter is used for transmission refinement and to improve edges on the image scene. The restored image then proceeds to the post-processing stage for contrast enhancement and gamma correction. Histogram equalization technique is used for contrast enhancement and gamma correction is used to improve the brightness of the image [7].

2.3 Combination of DDE and Fusion Dehazing

These two techniques were combined to produce an improved result. Initially, an input haze image was implementing DDE technique to produce the result. After that, the second technique which is Fusion Dehazing applied to the produced result. This combination generates two cycles of dehazing methods as figured in Figure 4.

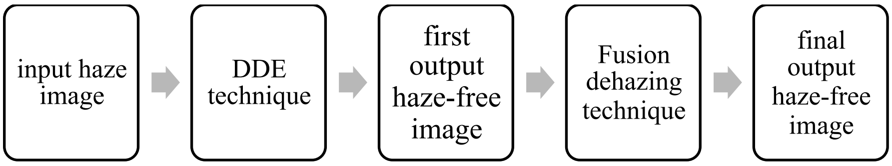

Fig. 4. The step of combination dehazing technique

3 Result and Discussion

This combination technique was implemented using MATLAB (2017b) environment on a computer with Intel i5-7200 CPU @ 2.5GHz with 8GB of RAM. The indoor dataset provided from Middlebury Stereo Datasets with its corresponding ground truth image and a depth map for haze simulation while the outdoor datasets uses real-world haze images. The synthetic haze in an image was simulated with atmospheric scattering model presented in [1].

The result will be compared to the five state-of-the-art dehazing methods: He et al. [3], Zhu et al. [4], Berman et al. [2], Ren et al. [6], Cai et al. [5], and evaluated with image quality assessment MSE, PSNR, and SSIM [10].

Fig. 5. The comparison result with real-world outdoor haze image

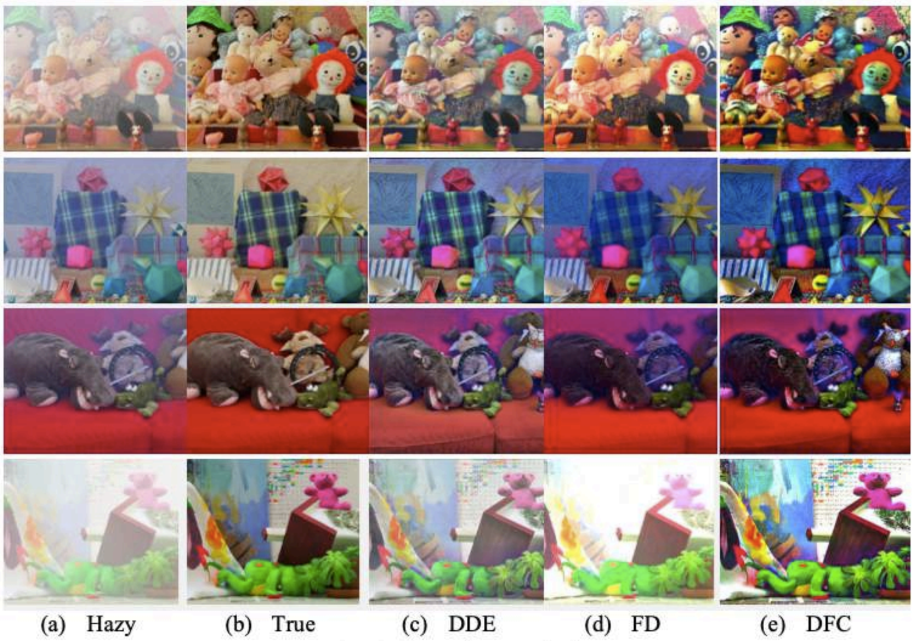

Fig. 6. Comparison analysis

Figure 5 and Figure 6 shows the result from DDE, Fusion Dehazing and our proposed technique which named as Detail Fusion Combination (DFC). As shown in that figure, the first applied technique was good in reducing the total amount of haze. While the second technique was enhancing the contrast of the image. Finally, our combined technique produces the new result. However, our result has the tendency to oversaturate, especially in the sky area.

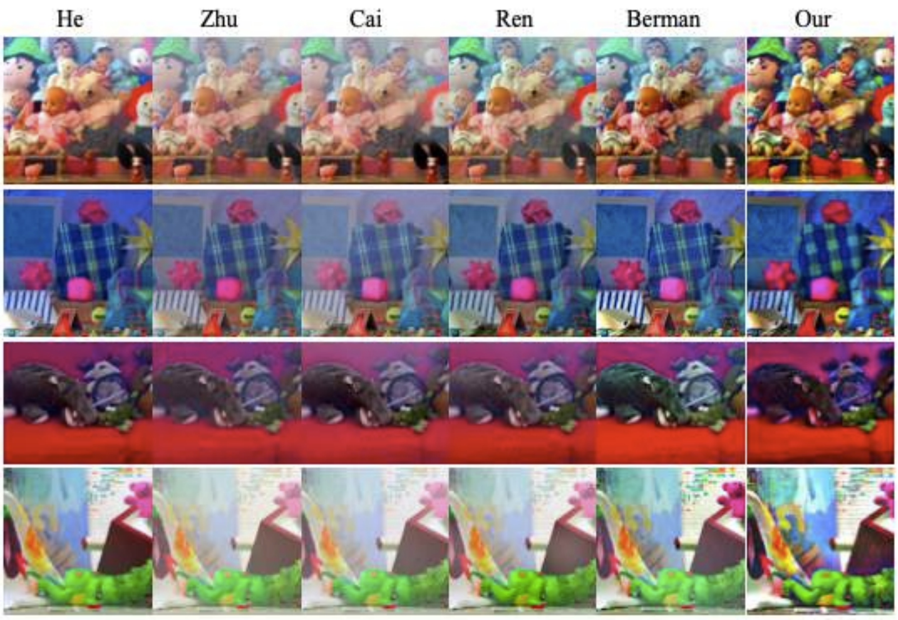

Fig. 7. The Comparison Result of The Combined Framework

Table 1. The comparative analysis using the MSE, PSNR and SSIM

	IQA (*dB*)	He	Zhu	Cai	Ren	Berman	DFC
	MSE	0.0222	0.0219	0.0237	**0.0203**	0.0270	0.0350
Dolls	PSNR	16.5453	16.5904	16.2483	**16.9335**	15.6917	14.5599
	SSIM	0.6637	0.6956	0.7079	**0.6530**	0.5659	0.4707
	MSE	0.0487	0.0157	**0.0123**	0.0230	0.0344	0.0678
Moebius	PSNR	13.1283	18.0533	**19.1126**	16.3807	14.6356	11.6873
	SSIM	0.3389	0.4433	**0.4253**	0.3543	0.3674	0.2504
	MSE	**0.0141**	0.0166	0.0214	0.0159	0.0188	0.0269
Couch	PSNR	**18.5231**	17.8059	16.6898	17.9926	17.2471	15.7032
	SSIM	**0.6980**	0.6608	0.6568	0.6780	0.5807	0.5705
	MSE	**0.0129**	0.0502	0.0512	0.0376	0.0284	0.0450
Teddy	PSNR	**18.8961**	12.9969	12.9050	14.2453	15.4704	13.4700
	SSIM	**0.9190**	0.8037	0.7891	0.86283	0.8439	0.5234

Figure 7 shows the result of our technique as compared to the five state-of-the-art dehazing techniques. Referring to Table 1, the resulting value of our technique is less satisfactory as compared to other methods. Nevertheless, our proposed technique is still relevant to the dehazing application.

4 Conclusion

This paper had proposed a new novel dehazing framework that combined two dehazing techniques which were applied in tandem. The first applied technique is Detail and Dehaze Enhancement and followed by Fusion Dehazing technique. Each technique is capable to produce a haze-free image respectively. But, those techniques have their own strengths and weaknesses. By combining the two techniques, we were confident to produce a better result and achieved our objective of removing haze from a single image. Nevertheless, the evaluation with state-of-the-art dehazing methods only generates a satisfactory measurement. In future research, we hope to improve this result with additional post-processing or enhancement to better result.

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