International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 4 (2015) pp. 10079-10086

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An Edge Preserving Smoothening Filter For Visibility Restoration of Hazy Images

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Abstract

The fog and haze present in the atmosphere causes the degradation of the colour and contrast in the outdoor images and also affects the efficiency of image processing algorithms. Hence, a proper visibility restoration algorithm is required which can remove the fog and also preserve the scene. The visibility restoration algorithms are classified as enhancement based and restoration based. Nowadays the later based methods are used with a single image input. All the earlier algorithms have the problem of removing fog near depth discontinuity. Hence, an edge preserving filter is incorporated into the Tarel's model which has better restoration capabilities.This method is ideal for real time applications like driver assistance, lane marking etc. Quantitative and qualitative evaluation from the results proves that it gives good results.

Keyword: Visibility restoration, air-light, dark channel, transmission map.

Introduction

The vision system works on the premise that the observer is in a transparent medium and the light rays from the scene travel to observer without attenuation and scattering. This is a true case for a normal day. But a typical day isnot normal and the vision systems must take into consideration the adverse weather conditions like fog, haze, rain, smoke, snow etc. The light upon interaction with the particles in these conditions undergoes attenuation, scattering, absorption and emission. The main objective of this work is to remove the unwanted effects of this atmospheric interactions and recovery of the image from it. The effects of fog on the scene are summed up by Koschmeider as the combined effect of attenuation and air light.

$$I(x,y) = R(x,y)e^{-kd(x,y)} + I_s(1 - e^{-kd(x,y)}) \quad (1)$$

Equation (1)is the Koschmeider relation showing the effect of attenuation and air-light where I(x,y) is the observed image intensity at pixel (x,y), k is the extinction coefficient of the atmosphere and d(x,y) is the depth between scene and camera, R(x,y) is the image intensity without haze, $I_s$is the source light .This is the basis of many modern day image restoration algorithms.

Tarel and Hautiere proposed a fast highly perceptual image restoration algorithm. This method assumes the air-light as a percentage between the local standard deviation and the local mean of the whiteness. This method is based on linear operations, but requires adjusting many parameters.[1]. He *et al*, proposed a method based on the soft matting and dark channel prior from a single colour or grey scale image. Dark channel prior is based on a key observation that most local patches in foggy outdoor images, except sky region, contain pixels which have low intensities in at least one colour component [2]. Oakley and Bu expressed a statistical model for scene content that gives a way of detecting the presence of air light in an arbitrary image. Here, level of air light is estimated under the assumption that air light is constant throughout the image. This method involves the minimization of a scalar global cost function and does not require image region segmentation. This method is applicable to both grey and colourimages [3].Kim *et al.* improved the method proposed by Oakley and Bu to make it applicable even when air-light is not uniform over the image. A cost function based on human visual model is used in luminance image to estimate the air light. The luminance image is estimated by the fusion of R, G, and B colour component. The air light map is generated using linear regression, which models the relationship between regional air-light and the coordinates of the image pixels.[4].

But all these algorithms have a common problem of removing fog near depth discontinuity. Hence an edge preserving filters like bilateral [5] and L0 gradient filters[6]are used. The L0 filter is a global edge preserving filter and the bilateral filter is a local edge preserving filter which helps in removing the fog in the places of large depth discontinuities. The filter is incorporated into Tarel's model[1], so that it has the advantage of speed of the Tarel's model. Hence this algorithm is more effective than the other restoration algorithms.

Background

The main idea of this paper is derived from the Tarel's algorithm.The Koschmeider equation is the basis of this algorithm. It is rewritten by introducing the atmospheric veil V(x,y) where

V(x,y) = $I_s(1 - e^{-kd(x,y)}$).Hence the whole relation can be reformed as

$$I(x,y) = R(x,y)\left(1 - \frac{V(x,y)}{I_s}\right) + V(x,y) \quad (2)$$

where I(x, y) is the observed image intensity (grey level or RGB) at pixel (x, y). The visibility restoration algorithm is decomposed into 5 steps.

1. Estimation of atmospheric light(I_s)
2. Atmospheric veil, V (x, y) from I(x, y)
3. Estimation of R(x, y) by inversing the equation(2)
4. Smoothing to handle noise amplification and

5. Final tone mapping.

The estimation of the atmospheric veil in Tarel’s model is estimated as the difference between the local average and the local standard deviation of whiteness[1]. The median filter is used for this process in Tarel’s algorithm. The advantage of this method is the speed and hence can be used for real time applications. But the main disadvantage of this method is that the restored image has very high saturation and fog is not removed at large depth discontinuities. This problem can be overcome with the help of edge preserving filters. The edge preserving filters are those which donot smooth the edges to such extent that they perish. Hence edges are preserved in the image and the fog can be removed easily from the edges.

Proposed Algorithm

This algorithm is backed by the Tarel’s model. The drawback of Tarel’s algorithm is overcome, by using edge preserving smoothing filter, with the help of the L0 gradient filter and bilateral filter. This combined filter is the replacement of the median filter in the Tarel’s model which shows improvement in speed. The framework of Tarel’s algorithm is shown in figure(1).

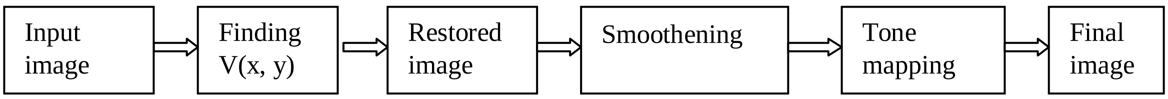

Figure 1: Frame work of Tarel’s algorithm

A. The Atmospheric veil inference

It is estimated as the difference between the local weighted average and the standard deviation of whiteness. White balance is performed on the input image initially. The first step of image restoration consists in inferring the atmospheric veil V (x, y). Due to its physical properties, the atmospheric veil is subject to two constraints when the observed image is known: it is positive 0 ≤ V (x, y) and being pure white, for each pixel, it cannot be higher than the minimum of the components of I(x,y) [1]. If the obtained atmospheric veil, V (x, y) does not seem so different, an incorrect halo appears when complete smoothness is enforced. This implies that the local average of minimum component of white balanced hazy image W(x, y)must be performed using a smoothing algorithm which preserves large jumps along edges. To perform an edge preserving smoothing, robust bilateral filter is used. The local weighted average of W(x,y) is computed as A(x,y) = bilateralfilter(W(x,y)) under a window of size S_{v}.According to Tarel’salgorithm, standard deviation is obtained by subtracting W(x,y) from A(x,y). In order to remove fog near depth discontinuity a global filter, L0 gradient filter is applied on (W(x,y)-A(x,y)). The atmospheric veil is hence the difference between A(x,y) and this standard deviation.Thus atmospheric veil is represented as B(x,y) = A(x,y) – L0gradient(W(x,y)-A(x,y)). The factor ρ is multiplied which denotes the percentage of restoration.

The atmospheric veil or airlight can be obtained by performing the following steps,

Step1:A(x, y) =bilateralfilter(W(x, y)) where, W(x,y) is minimum component of white balanced hazy image I(x,y).

Step2:B(x, y) = A(x, y) –L0Gradientfilter[(|W − A|)(x, y)]

Step3:V (x, y) = max(min(ρ B(x, y),W(x, y)), 0) (3)

By applying the bilateral filter and L0 gradient filter fog at the edges are removed and computation time is reduced.

B. Restoration of image

The inverse Koschmeider law is used to find the restored image. The equation corresponding to restored image is given as

$$R(x,y) = \frac{I(x,y) - V(x,y)}{1 - \frac{V(x,y)}{Is}} \quad (4)$$

According to Tarel's algorithm Is is set to (1,1,1) after performing white balance on input hazy image. ρ and s_v control the strength of restoration and is set between 90 – 95 % to prevent over saturation and under saturation. The parameter s_v specifies the larger size of the assumed white objects. Any close to white object with a size larger than s_v is assumed to be white because of the fog. On the contrary, a white object with a size smaller than s_v will be assumed intrinsically as white. Atmospheric veil is calculated considering the window size s_v=41 and ρ=0.95.

C. Smoothening

During the restoration process the more the atmospheric veil is important the more increases in the contrast. This will also amplify thenoise and image compression artifacts. Hence in order to soften these we need a local smoothening. The smoothening technique was carried similar to Tarel's work.

D. Tone mapping

This is done to make the colour of the restored image to match the original scene colour. The restoration process usually makes the image look over saturated and unrealistic. For this we do a linear mapping between the log original and log restored image which makes the original and the restored image have the same mean and standard deviation.

The image thus obtained finally will be fog free and the edges are also preserved. Hence to make use of the edge preserving capabilities of the L0 filter and of the bilateral filter, we combine them and replace the median filter in the Tarel's model. Therefore, the whole idea of restoration remains the same, for it uses the same Koschmeider relation, but the filter used for the purpose of fog removal changes. The results obtained from the subjective and the objective evaluations prove that the combined filter is more effective in removing the fog, preserving the edges and contrast management than the other algorithms.

Result

The effectiveness of the proposed algorithm in removing the fog from the images is demonstrated by applying the algorithm on several images. These images range from sky scrapers to the forest areas. There are two kinds of analysis involved in the comparison between various algorithms.

A. Subjective Evaluation

Fig. 2.shows the restored image of Tarel's algorithm using Median filterand our method using edge preserving smoothening filter like bilateral and L0 gradient filter. The highlighted portion on the image shows that the fog is not removed near depth discontinuity in Tarel's method, whereas, it is removed by using Bilateral and L0 gradient filters.

Figure 2 (a): Tarel's method **Figure 2(b):** our method

Figure 3:.Shows the comparison of various filters applied to hazy image

Fig.3 shows the comparison of various filters applied to hazy image using Tarel's algorithm. Replacing bilateral filter alone instead of median filter showed high quality image but the computation cost was high. So the work was carried in an objective to increase the visibility and decrease the computational cost by using both bilateral and L0 gradient filter.

B. Objective Evaluation

To quantitatively asses and rank the algorithms used for fog removal and restoration various indicatorslike entropy, PSNR, time and edge rate are calculated between the input image and the restoredimage.

a) The entropy is a statistical measure of randomness. Higher the measure indicates more details. Entropy is more, when bilateral and L0 gradient filters are used when compared to the other two filters, as shown in Table 1.
b) The peak signal to the noise ratio which should be greater for a better quality image is also more for the combined filter, as shown in Table2.
c) The entire algorithm is implemented using MATLAB 7. The time taken for the executionof the algorithm is calculated using tic and toc instruction.As the resolution increasesthe time taken for restoration increases in all the filters. The bilateral combined withL0 gradient filter takes the least time compared to median andbilateral as shown in Table 3.
d) The edge rate is the number of new edges created in the restored image after the application of the algorithm as shown in Table 4.

Table 1: Entrophy

IMAGES (entropy) with resolution	MEDIAN	BILATERAL	COMBINED
Image 1 (420 x 1890)	7.854	7.88	7.955
Image 2 (600x1200)	7.0029	7.124	7.18
Image 3 (450x1800)	7.637	7.67	7.67
Image 4 (480x1920)	6.962	7.03	7.09
Image 5 (683x3072)	7.515	7.51	7.467
Image 6 (768x3072)	7.548	7.478	7.577
Image 7 (400x1800)	6.858	6.73	6.739
Image 8 (227x666)	7.472	7.371	7.48
Image 9 (400x1800)	7.598	7.583	7.665
Image 10 (183x825)	7.6257	7.617	7.693
Average	**7.40726**	**7.3993**	**7.4516**

Table 2: PSNR

IMAGES	MEDIAN	BILATERAL	COMBINED
Image 1 (420 x 1890)	62.340	64.06	64.85
Image 2 (600x1200)	58.54	58.85	59.45
Image 3 (450x1800)	60.285	60.30	60.57
Image 4 (480x1920)	64.829	64.89	65.17

Image 5 (683x3072)	63.104	63.73	63.93
Image 6 (768x3072)	62.8313	62.71	62.864
Image 7 (400x1800)	63.337	63.89	64.615
Image 8 (227x666)	60.186	60.314	60.567
Image 9 (400x1800)	63.2131	63.39	63.432
Image 10 (183x825)	59.696	59.85	60.59
Average	**61.83614**	**62.1984**	**62.6038**

Table 3: Computation Time (Seconds)

IMAGES	**MEDIAN**	**BILATERAL**	**COMBINED**
Image 1 (420 x 1890)	5.823	15.20	9.61
Image 2 (600x1200)	10.89	14.57	9.49
Image 3 (450x1800)	6.719	15.82	9.96
Image 4 (480x1920)	6.717	17.38	10.99
Image 5 (683x3072)	35.364	37.66	31.65
Image 6 (768x3072)	46.714	42.41	26.46
Image 7 (400x1800)	6.716	14.26	9.01
Image 8 (227x666)	1.18	4.21	3.02
Image 9 (400x1800)	6.17	14.17	9.011
Image 10 (183x825)	1.19	4.17	2.88
Average	**12.7483**	**17.985**	**12.2081**

Table 4: EDGE RATE

IMAGES	**MEDIAN**	**BILATERAL**	**COMBINED**
Image 1 (420 x 1890)	0.118	0.344	0.36
Image 2 (600x1200)	0.189	0.34	0.40
Image 3 (450x1800)	0.0328	0.06	0.08
Image 4 (480x1920)	0.328	0.48	0.69
Image 5 (683x3072)	0.144	0.49	0.43
Image 6 (768x3072)	0.067	0.168	0.169
Image 7 (400x1800)	0.190	0.439	0.446
Image 8 (227x666)	0.2737	0.3483	0.3916
Image 9 (400x1800)	0.09	0.221	0.1976
Image 10 (183x825)	0.318	0.4662	0.498
Average	**0.17505**	**0.33565**	**0.36622**

Conclusion

Fog is the most natural phenomenon. The images taken in extreme weather conditions are hence prone to haze, fog, rain and hence inherent noise. Various defogging algorithms are available for the removal of the effect caused by this fog. They range from multiple image input requirement, which contains image of the scene in different weather conditions to a single image. The Koschmeider equation represents the image in foggy atmosphere. The equation can be inversed to get the restored image. The base of the algorithm used here is the Tarel's model which uses the median filter to remove the fog. The main advantage of this model is speed, so that this can be used in real time applications like autonomous navigation. But the median filter makes the restored image unrealistic with over saturation. The colour of the scene totally changes. Hence this method is not applicable when quality of the image is more important like identifying crime scenes, mapping. Hence there is a necessity of a filter which canpreserve the edges, retain the original colour of the scene, and remove fog at large depth discontinuities all the while being reasonably fast. Therefore filters like bilateral and L0 gradient are used.

The bilateral filter being a reasonably a better edge preserving filter than the median don't highly saturate the restored image and also removes the fog better at the edges. But the time taken to remove the fog using bilateral alone is quite high and also the restored image is not up to the mark. Therefore we used the combination of L0 gradient and bilateral filter in place of the median filter in the Tarel's model. The restoration has all the advantages of the two filters and also relatively fast compared to the use of bilateral filter alone. Our method preserved the edges, removed the fog at the edges and retained the colour contrast. Therefore this algorithm produces better results than the previous models.

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