ENHANCEMENT OF COLOR IMAGES IN POOR VISIBILITY CONDITIONS

KokKeong Tan and John P. Oakley

Department of Electrical Engineering and Electronics
UMIST
P.O. Box 88, Manchester M60 1QD, United Kingdom.

ABSTRACT

Degradation of images by the atmosphere often restricts imaging applications to good visibility conditions. For example, when imaging the terrain from a forward-looking airborne camera, the atmospheric degradation causes both a loss in contrast and color information. Enhancement of such images is a difficult task due to the complexity in restoring both the luminance and chrominance while maintaining good color fidelity. One particular problem is the fact that the level of contrast loss depends strongly on wavelength; shorter wavelengths ie. blue are more effected. In this paper, a novel method is presented for the enhancement of color images. This method is based on the underlying physics of the degradation and the parameters required for enhancement are estimated from the image itself. The proposed method is tested using synthetic images to explore the limitations and reliability of the method under different visibility conditions. Enhancement is performed on real images taken using an airborne camera at a height of approximately 1000 meters in hazy conditions for which the visibility is approximately 10 kilometers. Significant improvements in terms of contrast, visible range and color fidelity are evident when compared to existing methods.

1. INTRODUCTION

Imaging in the atmosphere is often limited by atmospheric scattering caused by aerosols such as haze, fog, mist and cloud. The degree of scattering is dependent on the range (ie. distance from the camera to the imaged object) and wavelength of light. For color images taken from a forward-looking airborne camera, the range across the image is non-uniform. This results in a non-uniform loss of contrast and color fidelity across the image. This effect is evident in figures 2 and 8, which are taken from an airborne camera at a height of approximately 1000 meters in hazy conditions for which the visibile range is approximately 1 kilometer.

Image contrast enhancement algorithms can be divided into two main types – model-based and non-model-based. Model-based algorithms improve image contrast by reversing the underlying cause of image degradation whereas non-model-based algorithms require no information about the cause of degradation.

Perhaps the most important non-model-based algorithm is histogram equalization. For colour images, one method is first to perform a transformation from the RGB (red-green-blue) space into the HSI (luminance-hue-saturation) space [1]. Equalization is then performed on the luminance and saturation but not the hue so as to maintain the original color. However, the wavelength dependence of the atmosphere degrades the hue component as well. Therefore, this method does not fully restore color.

The alternative is to perform histogram equalization on the RGB color components [2]. However, this method will cause unwanted changes to the hue. Non-model-based algorithms have difficulty in maintaining good color fidelity.

Model-based algorithms are more reliable as they exploit the underlying physics of the degradation process. Among them are contributions by Yitzhaky, Dror and Kopeika [3] and Oakley and Satherley [4]. Yitzhaky, Dror and Kopeika [3] assume that the degradation is uniform across the image and detailed information about the atmospheric conditions in the form of aerosol size distribution are available during the imaging period. Their method is not applicable to the forward-looking camera since the degradation is not uniform in this case. Oakley and Satherley [4] suggest that image enhancement should be performed by compensating for the attenuation and scattering of light. Their model allows for a non-uniform degradation across the image and the required atmospheric parameters are estimated from the image itself. Neither of these algorithms operate with color images.

Support by the EPRSC is gratefully acknowledged.

2. THEORY

The geometry of an imaging scene from a forward-looking airborne camera is shown in figure 1. The irradiance on a particular sensor element of the CCD can be assumed to be the sum of two components – the irradiance due to reflection from the terrain surface and due to light scattered directly towards the sensor by the aerosol (denoted by A and B respectively in figure 1). The irradiance on sensor element k is denoted by $J_s(k)$ and is given as follows [4],

$$J_s(k) = \Omega_k I_0 [1 + (F_k - 1)\exp(-\beta_{sc} R_k)] \qquad (1)$$

where Ω_k is the solid angle imaged by sensor element k, I_0 the radiance of the sky, F_k the reflectance factor of the terrain area imaged by sensor element k and R_k is the range ie. the distance from sensor element k to the terrain area imaged by it (see figure 1). β_{sc} is a quantity proportional to the total scattered flux per unit length of light path known as the total volume scattering coefficient.

The enhanced image is taken to be the image of the reflectance factors (F_k). Ω_k is a known camera parameter and R_k can be obtained from the ray-tracing method using information of the altitude, tilt and position of the camera [4]. This leaves the atmospheric dependent parameters β_{sc} and I_0 which can be estimated statistically from the image itself. For a forward-looking camera, the variation in R_k across the image is exploited to estimate these

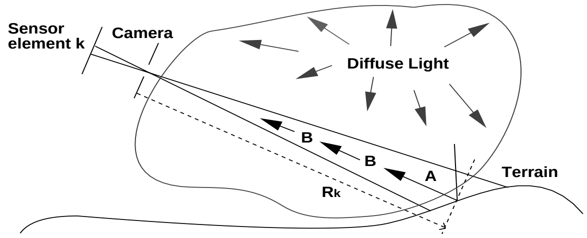

Fig. 1. Geometry of the imaging scene.

two parameters. A good estimation procedure is the maximum likelihood method using a Gaussian assumption for the distribution of reflectance factor [4].

The advantage of estimating β_{sc} from the image data is that information about atmospheric conditions is then not needed. In general, reliable estimates of β_{sc} are difficult and expensive to obtain. Once estimates for β_{sc} and I_0 are obtained, the reflectance factors can be obtained using the function

$$F_k = \left[\left(\frac{J_s(k)}{\Omega_k I_0} - 1 \right) \exp(\beta_{sc} R_k) \right] + 1 \qquad (2)$$

The wavelength of the light that reaches the CCD varies throughout the visible spectrum. The values of β_{sc} and I_0 varies with light wavelength [5][6]. For example, β_{sc} decreases with light wavelength [5]. In the enhancement of grayscale images [4], the estimate for β_{sc} and I_0 is represented by a single overall value for all light wavelengths. For color images, three values for β_{sc} and I_0 are obtained to represent each range of wavelengths (red, green and blue). Hence, the estimate for β_{sc} and I_0 is more accurate when enhancement is performed in color than in grayscale. In fact, better enhancement will result if the image can be seperated into more wavelength components.

3. EXPERIMENTAL PROCEDURE

A simple simulation was performed to explore the efficiency of the proposed method. Firstly, a synthetic terrain image was generated using knowledge of typical terrain cover distribution [7], terrain cover reflectance factors and solar radiation values [6]. This is achieved by dividing the generated terrain into equal areas. A terrain cover type is assigned to that area according to its probability of occurence [7] and the corresponding reflectance factor is then assigned to it. The synthetic terrain was then degraded using a β_{sc} value from 10^{-6} to 10^{-2} (visibility of approximately 4000 kilometers to 400 meters). These degraded images are enhanced using the proposed method and the results evaluated in terms of the color fidelity and visible range of the enhanced image.

To evaluate the color fidelity, every pixel of the enhanced image is plotted in the RGB cube. These pixels are then classified to the terrain cover type which reflectance factor is nearest to the enhanced pixel in the RGB cube. This is then compared with the undegraded image and the efficiency is taken to be the percentage of correct classification.

The visible range of the enhanced image is taken to be the maximum range where the ratio of the average reflectance factor of the undegraded image to the difference in reflectance factor value between the enhanced and undegraded image is more than unity. At this point, the error in the enhanced image (difference in reflectance factor value between the enhanced and undegraded image) is equal to the average signal (reflectance factor of the undegraded image).

After the efficiency of the proposed method was explored, the method was tested on real images taken by a forward-looking airborne SONY DX-151P video camera mounted on a BAe Jetstream aircraft flying at an altitude of approximately 1000 meters above sea-level. These flights were carried out over northwest England in hazy conditions. The video was digitised and enhanced off-line on a Silicon Graphics workstation. Two images from different video clips are shown in figures 2 and 8.

4. RESULTS

An enhanced image of figure 2 using the proposed method is shown in figure 3. For comparison, images enhanced using histogram equalization in the RGB space [2] and HSI space [1] are shown in figures 4 and 5 respectively. Another set of images from a different location are shown in figures 8 – 11 (arranged in the same order). It can be seen that the image enhanced using the proposed method is significantly better in terms of contrast, visible range and color fidelity than results from the other two methods.

Fig. 2. Image taken by an airborne camera at a height of approximately 1000 meters in hazy conditions (All images are best viewed in color).

Fig. 3. Image in figure 2 enhanced using the proposed method.

The estimated parameters for the red, green and blue images are shown in table 1 for both images. From ref. [5], the total volume scattering coefficient can be approximated by

Fig. 4. Image in figure 2 enhanced using histogram equalization in RGB space [2].

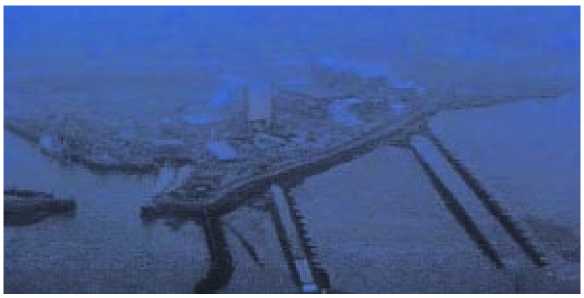

Fig. 5. Image in figure 2 enhanced using histogram equalization in HSI space [1].

$$\beta_{sc} = constant \frac{1}{\lambda^{v-2}} \qquad (3)$$

where v varies from 6 for very clear conditions to practically 2 for foggy conditions[5]. Using the estimated values of β_{sc} in table 1 for the red, green and blue images, the value of v was found to have an average value of 2.41 and 3.33 for figures 2 and 8 respectively. This is consistent with experimental values determined by Volz [5] in hazy conditions of $2.12 < \gamma < 4.3$. The difference between the value obtained from figures 2 and 8 is caused by the different visibility conditions[1]. The esimated values for I_0 indicates that the blue component of the solar radiance is larger than the red component. This is also consistent with calculated and measured results in ref. [6]

Using the degraded synthetic image, the plots of efficiency in terms of color fidelity and visible range of the enhanced synthetic images for a β_{sc} from 10^{-6} to 10^{-2} are shown in figures 6 and 7 respectively. The theoretical visible range is shown by the dotted line in figure 7.

In figure 6, for low β_{sc} where image degradation is almost negligable, the efficiency is close to 100%. From a β_{sc} of $5(10^{-5})$, the efficiency decreases due to an increase in image degradation till about $1(10^{-3})$ where the efficiency falls to zero. A similar explanation is valid for figure 7 where the visible range is maximum at $\beta_{sc} < 5(10^{-5})$ and decreases to its minimum at $\beta_{sc} > 1(10^{-3})$.

[1]From the β_{sc} values in table 1, figure 2 was taken in clearer conditions than figure 8. This is not obvious in the images as the aircraft was flying at a higher altitude in figure 2 than in figure 8

Inout Image		β_{sc}	I_0
Figure 2	Red	$6.2(10^{-5})$	0.34
	Green	$6.7(10^{-5})$	0.48
	Blue	$7.2(10^{-5})$	0.95
Figure 8	Red	$2.8(10^{-4})$	0.49
	Green	$3.0(10^{-4})$	0.76
	Blue	$4.6(10^{-4})$	1.09

Table 1. Estimated parameters for figures 2 and 8.

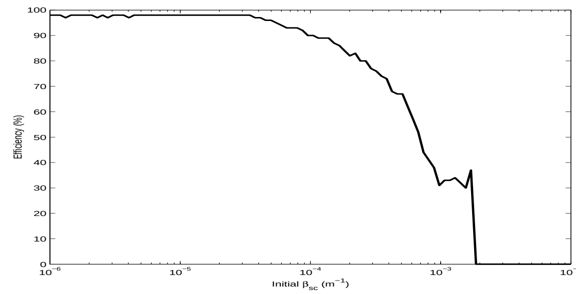

Fig. 6. Efficiency in terms of colour fidelity for different values of β_{sc}.

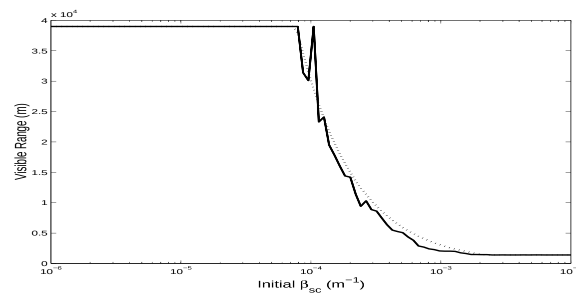

Fig. 7. Efficiency in terms of visible range for different values of β_{sc}.

This is consistent with the expected visible range shown by the dotted line.

Each image pixel in figures 8 – 11 were classified to the terrain cover type of ref. [7] that has a reflectance factor nearest to the reflectance factor of the pixel in the RGB cube. The average classification error ie. average difference in cover distribution between the above and survey data [7], for each of the four images are shown in table 2. The image enhanced using the proposed method gives the lowest classification error and this value is close to the expected value obtained in figure 6 of 26% at a β_{sc} value of $4.6(10^{-4})$.

The visible range of figures 8 – 11 obtained by averaging visible inspection results of 20 people[2] are shown in table 2. The visible range of the image enhanced using the proposed method is

[2]A approach similar to the one used in finding the visible range of the synthetic images is not possible as information of the actual reflectance factors of the terrain is not available

Figure	Classification Error	Visible Range (km)
8 (Original image)	28.48%	0.85
10 (HE in RGB space)	22.91%	0.72
11 (HE in HSI space)	28.05%	0.67
9 (Proposed Method)	14.96%	1.53

Table 2. Average Classification Error and visible range for figures 8 to 9. (HE - Histogram Equalisation)

higher than all the other enhancement methods.

5. CONCLUSION

A novel method is presented in this paper which can enhance color images degraded by the atmosphere. The main advantages of this method are : (1) The ability to enhance color fidelity (2) The improvement in contrast when compared to existing methods and (3) The significantly better visible range when compared with existing methods.

The estimates of extinction coefficient, a by-product of the proposed image enhancement method, are consistent with previous work on atmospheric optics [5][6]. The efficiency of the method with real images in terms of both color fidelity and visible range is close to that predicted from simulation using synthetic images. The simulation results also show that the method should be applicable to a wide range of visibility conditions.

Fig. 8. Image taken by an airborne camera at a height of approximately 1000 meters in hazy conditions.

Fig. 9. Image in figure 8 enhanced using the proposed method.

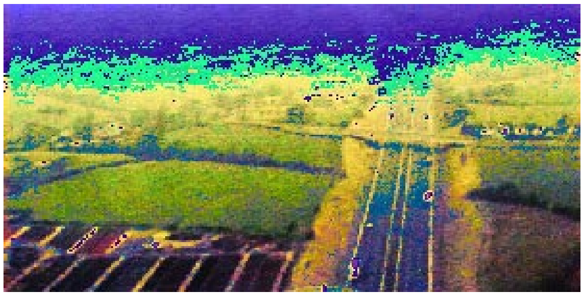

Fig. 10. Image in figure 8 enhanced using histogram equalization in RGB space [2].

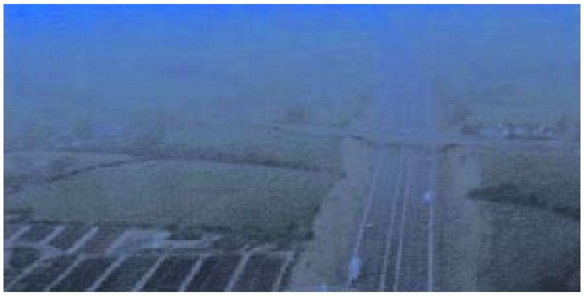

Fig. 11. Image in figure 8 enhanced using histogram equalization in HSI space [1].

6. REFERENCES

[1] I. Pitas and P. Kiniklis, "Multichannel Techniques in Color Image Enhancement and Modelling," IEEE Trans. Image Process., vol. 5, pp. 168-171, 1996.

[2] W. Niblack "An Intorduction to Digital Image Processing," Prentice Hall, 2nd ed., 1986.

[3] Y. Yitzhaky, I. Dror and N. S. Kopeika, "Restoration of atmospherically blurred images according to weather-predicted atmospheric modulation transfer functions," Optical Eng., vol. 36, pp. 3064-3072, 1997.

[4] J. P. Oakley and B. L. Satherley, "Improving Image Quality in Poor Visibility Conditions Using a Physical Model for Contrast Degradation," IEEE Trans. Image Process., vol. 7, pp. 167-179, 1998.

[5] E. J. McCartney, "Optics of the Atmosphere," John Wiley, 1976.

[6] M. Iqbal, "An Introduction to Solar Radiation," Academic Press, 1983.

[7] R. M. Fuller, B. K. Wyatt and C. J. Barr, "Countryside survey from ground and space," J. Environmental Management, vol. 54, pp. 101-126, 1998.