A novel haze image enhancement algorithm

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Abstract. The atmospheric scattering model (ASM) is usually used in the haze image enhancement. Researchers always assume that the scene incident light is fixed, which is unreasonable in the real environment. In this paper, an improved atmospheric scattering model (IASM) with the incident light redefined is proposed to enhance the haze images. Firstly, the bright channel map and fuzzy clustering algorithm are used to divide the haze image into different scenes and estimate the incident light of each scene. Secondly, the atmospheric light is estimated based on the sky area location and the transmittance. Finally, the albedo of the image is restored through the IASM. The experiments show that the proposed algorithm is effective in enhancing the haze image.

1. Introduction

The contrast, visibility and color fidelity of haze images are prone to degradation [1]. Researchers always use the atmospheric scattering model to enhance the haze image. For example, He proposed the well-known dark channel prior [2]. Zhu constructed a linear model which is used for estimating the scene depth of the haze image [3]. Li introduced a new global guided image filtering in image dehazing [4]. The scene incident light (SIL) in these atmospheric scattering models consist of atmospheric light which is regarded as a global constant. In fact, the scene incident light also includes scene reflection light, background reflection light, and atmospheric scattering light [5]. Therefore, the SIL is not a global constant. Thus, the dehazing algorithms based on the traditional ASM is always invalid under outdoor environment.

To solve the problem mentioned above, an image enhancement algorithm based on IASM is proposed. First of all, the bright channel map and fuzzy clustering algorithm are used to divide the haze image into four independent scenes with the strongest illumination, medium-strong illumination, medium-weak illumination, and weakest illumination. And then the incident light of each scene is estimated. Also, the atmospheric light is estimated by the sky area position and the transmittance. Finally, the albedo of the image is restored through the improved atmospheric scattering model. The experimental results show that the proposed algorithm can effectively solves the problems of low brightness and low contrast and over-saturation of images.

2. Image enhancement algorithm based on improved haze imaging model

2.1 The proposed IASM

The ASM is a physical model established in the analysis and evaluation of the influence of atmospheric on imaging and the interaction of light and transmission medium [6, 7]. The model expression is [6]:

[Equation]
\[ E(x, y) = E_\infty \cdot i(x, y) \cdot e^{-\beta d(x, y)} + E_\infty \cdot (1 - e^{-\beta d(x, y)}) \]

where \( E(x, y) \) refers to the pixel intensity value. \( E_\infty \) stands for the atmospheric light. \( e^{-\beta d(x, y)} \) refers to the transmission. \( d \) refers to the distance from the scene to the camera. \( \beta \) refers to the atmospheric scattering coefficient.

When the illumination of the image scene is not uniform, the scene incident light is not a constant. Scene incident light also includes scene reflection light, background refracted light, atmospheric scattering light, etc. In this paper, we estimate the scene incident light for each independent scene. Firstly, we use the brightness channel prior \([8]\) to evaluate the overall illumination of haze images. Then, the fuzzy c-means clustering (FCM) \([9]\) is used to divided the brightness channel map into four independent scenes with the strongest illumination, medium-strong illumination, medium-weak illumination, and weakest illumination. After clustering, we use the Guided Filter algorithm \([5]\) to obtain the scene incident light map with more abundant edge information. The improved atmospheric scattering model is:

\[ E(x, y) = L(x, y) \cdot i(x, y) \cdot e^{-\beta d(x, y)} + E_\infty \cdot (1 - e^{-\beta d(x, y)}) \]

where \( L(x, y) \) refers to the scene incident light value corresponding to each pixel.

### 2.2 Atmospheric light estimation

The estimation of \( E_\infty \) is important. Thus, we give a calculation method of estimating \( E_\infty \). First, we designed a weight function to locate the region where atmospheric light is located:

\[ \Gamma(x, y) = e^{ap(x) - bt(x, y)} + c, \quad p(x) = \frac{l - x}{x} \]

where \( p \) is a position function of the sky area. \( l \) is the image height. \( t(x, y) \) is the transmission calculated by using the He algorithm \([2]\). \( a, b, c \) are the parameter adjustment factors.

Then, the located atmospheric light can be estimated as follows:

\[ E_\infty = \frac{1}{K} \sum_{(x, y) \in \Lambda_{pre}} \Gamma(x, y) E(x, y), K = \sum_{(x, y) \in \Lambda_{pre}} \Gamma(x, y) \]

where \( K \) is the normalization factor. \( \Lambda_{pre} \) is a candidate region for the region where atmospheric light is located.

### 3. Experiments

In order to verify the effectiveness of the proposed dehazing algorithm, the proposed algorithm of is compared with the classic dehazing algorithms. Figure 1 shows the dehazing results of the proposed dehazing algorithm and the five classical dehazing algorithms. Figure 1(a) shows different types of haze images. Figure 1(b)-(f) show the results of the dehazing algorithms of Kopf \([9]\), Tan \([10]\), Fattal \([11]\), Tarel \([12]\), He \([13]\), respectively. Figure 1(g) shows the dehazing results of the proposed algorithm of this paper. As we can see from Figure 1. The proposed algorithm can obtain the better dehazing effect than other algorithm mentioned above.

Table 1 shows the performance indicators of all the images in Figure 1. A large number of comparative experimental results show that the proposed dehazing algorithm in this paper is able to obtain haze-free images of higher quality with rich details and a few halo artifacts. It can be seen that the average value, entropy, PSNR and SSIM of the images are all relatively improved.
Figure 1. Qualitative comparison of classic dehazing algorithms: (a) The original images; (b) Kopf’s; (c) Tan’s; (d) Fattal’s; (e) Tarel’s; (f) He’s; (g) The proposed

Table 1. Comparisons of dehazing performances in Figure 1

| Test images       | Indictor | Kopf | Tan  | Fattal | Tarel  | He   | The pro |
|-------------------|----------|------|------|--------|--------|------|---------|
|                   | Mean     | 0.567| 0.394| 0.553  | 0.392  | 0.395| 0.508   |
| The first image   | Entropy  | 15.515| 17.046| 16.743 | 14.143 | 17.384| 17.766  |
| (1024×768)       | PSNR     | 18.127| 12.763| 21.351 | 13.512 | 14.388| 17.506  |
|                   | SSIM     | 0.878 | 0.776 | 0.914  | 0.838  | 0.845| 0.8701  |
|                   | Time/s   | 58.765| >100 | 16.157 | 69.294 | 35.896| 29.512  |
| The second image  | Mean     | 0.492 | 0.363 | 0.420  | 0.457  | 0.428| 0.506   |
| (576×768)        | Entropy  | 14.503| 15.260| 15.410 | 16.661 | 15.645| 16.014  |
|                   | PSNR     | 18.817| 11.710| 16.152 | 16.978 | 15.874| 17.735  |
|                   | SSIM     | 0.914 | 0.647 | 0.879  | 0.848  | 0.900| 0.916   |
|                   | Time/s   | 26.766| >100 | 10.612 | 18.765 | 14.234| 16.331  |
| The third image   | Mean     | 0.467 | 0.376 | 0.417  | 0.446  | 0.359| 0.489   |
| (576×768)        | Entropy  | 15.901| 15.274| 16.220 | 17.585 | 16.517| 17.308  |
|                   | PSNR     | 18.223| 12.143| 17.115 | 17.369 | 13.021| 17.180  |
|                   | SSIM     | 0.888 | 0.726 | 0.890  | 0.850  | 0.832| 0.853   |
|                   | Time/s   | 23.981| >100 | 8.954  | 20.342 | 16.431| 15.007  |
| The forth image   | Mean     | 0.547 | 0.414 | 0.521  | 0.453  | 0.479| 0.517   |
| (576×768)        | Entropy  | 15.965| 15.872| 16.401 | 17.676 | 16.643| 17.210  |
|                   | PSNR     | 18.315| 11.812| 17.213 | 16.375 | 14.112| 17.213  |
|                   | SSIM     | 0.876 | 0.723 | 0.873  | 0.834  | 0.845| 0.886   |
|                   | Time/s   | 21.767| >100 | 8.567  | 21.236 | 11.348| 13.890  |

4. Conclusion
A haze image enhancement algorithm based on IASM is proposed in this paper. Compared with the traditional model, the proposed model with the incident light redefined can obtain more reliable results. The visual effect of dehazing images is more natural and the performance indicators are better.
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References
[1] Ju M, Zhang D, Wang X. Single Image Dehazing Via an Improved Atmospheric Scattering Model [J]. Visual Computer, 2017, 33(12): 1613-1625.
[2] Zhu Q, Mai J, Shao L. A Fast Single Image Haze Removal Algorithm Using Color Attenuation Prior[J]. IEEE Transactions on Image Processing, 2015, 24(11): 3522.
[3] Li Z, Zheng J, Single Image De-Hazing Using Globally Guided Image Filtering[J]. IEEE Transactions on Image Processing, 2018, 27(1): 442-450.
[4] Lalonde J F, Efros A A, Narasimhan S G. Estimating the Natural Illumination Conditions from a Single Outdoor Image[J]. International Journal of Computer Vision, 2012, 98(2): 123-145.
[5] Yu J, Xu D B, Liao Q M. Image defogging: a survey[J]. Journal of Image and Graphics, 2011, 16(9): 1561-1576.
[6] Gu Z, Ju M, Zhang D. A novel Retinex image enhancement approach via brightness channel prior and change of detail prior[J]. Pattern Recognition & Image Analysis, 2017, 27(2):234-242.
[7] Qamar U. A dissimilarity measure based Fuzzy c-means (FCM) clustering algorithm[J]. Journal of Intelligent & Fuzzy Systems, 2014, 26(1): 229-238.
[8] Kopf J, Neubert B, Chen B, et al. Deep photo: model-based photograph enhancement and viewing[J]. Acm Transactions on Graphics, 2008, 27(5): 1-10.
[9] Tan R T. Visibility in bad weather from a single image[C]. Computer Vision and Pattern Recognition, 2008. CVPR 2008. IEEE Conference on. IEEE, 2008: 1-8.
[10] Fattal R. Single image dehazing[J]. ACM Transactions on Graphics, 2008, 27(3): 72.
[11] Tarel J P, Hautière N. Fast visibility restoration from a single color or gray level image[J]. 2009, 30(2): 2201-2208.
[12] He K, Sun J, Tang X. Single Image Haze Removal Using Dark Channel Prior[J]. IEEE Transactions on Pattern Analysis & Machine Intelligence, 2011, 33(12): 2341-2353.