Unmanned aerial vehicle (UAV) image haze removal using dark channel prior

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Abstract. The unmanned aerial vehicle (UAV) image taken in foggy or haze weather usually has lower contrast and fidelity, the quality of the image is seriously degraded. In this paper, we propose a dehazing model based on dark channel prior to dehaze the UAV image. We use a quad-tree hierarchical searching method to estimate the atmospheric light value, it can effectively avoid the influence of white objects in the image on the estimation of atmospheric light values. In the process of refining the medium transmission map, we propose a new regularization optimization scheme. Experimental results show that the proposed approach effectively recover the clear UAV image.

1. Introduction
UAV remote sensing system plays an important role in resource detection [1], emergency rescue [2] and disaster detection [3]. However, the UAV images taken in haze weather environment has low contrast. The image details are blurred, which seriously affects the quality of UAV images. The objective feature extraction and post-processing of image are affected. Therefore, the haze removal algorithm of UAV image have high research and practical value.

Recently, single image haze removal has been a hot spot of research given its wider application range. Tan et al. [4] directly maximize the contrast of the dehazed image since haze-free images have higher contrast than hazy ones. The results of this method often present severe color distortion. Fattal [5] assumed that the reflectivity of local small image blocks is constant, and estimated the reflectivity by independent component analysis. The real scene restored by this method has a lot of noise. Tarel et al. [6] proposed a new median filter to dehaze the image, and applied the algorithm to the vehicle camera. The edge information of the dehazed image is not well preserved; He et al. [7] proposed a dark channel prior for natural outdoor images, which asserts that the local minimum of dark channel (minimum of R, G, B channels) of a haze-free image is close to zero. Dark channel prior is physically sound and generates good results, but this method failed in the sky or white area; Meng et al. [8] proposed an effective regularization dehazing method to restore haze-free images by exploring the inherent boundary constraint; Zhu et al. [9] created a linear model to estimate the depth of haze scenes based on Color Attenuation Prior (CAP) and trained the parameters of the model using supervised learning method. The model can quickly recover the haze-free image; Tang et al. [10] combine four types of haze-relevant features with Random Forest to estimate the transmission. This algorithm has high complexity and lower efficiency; Fattal et al. [11] proposed a haze removal algorithm based on the color-lines. The image taken by haze weather makes the color line shift. The author estimates the
medium transmission map based on the shift between color line and the origin, and uses Markov random field (MRF) model to regularized the medium transmission map, so as to restore a more accurate haze-free image; Berman et al. [12] proposed an algorithm based on non-local prior, the medium transmission was estimated by haze-lines of every pixel. This algorithm is linear and requires no training;

However, the above methods are mostly only for general outdoor hazy images and lack applicability for dehazing UAV reconnaissance images. Huang et al [13] proposed an algorithm for dehazing UAV reconnaissance images based on layered scattering model. Due to the characteristics of UAV reconnaissance images, the distance between the imaging device and the imaging target is very long. The aerosol concentration of atmosphere environment around the imaging device is very different from that of atmosphere environment around the imaging target, leading to the extinction coefficient is not a constant, so the author calculate the atmospheric light and extinction coefficient of the layered model in order to achieve the restored image; Zhang et al [14] proposed a fast haze removal algorithm based on dark channel prior, the fast guided filter [15] is used to the refine the medium transmission. Although the running speed of the algorithm has been greatly improved, but the clarity of the dehazed UAV images is not impressive.

The UAV image is different from other images. Since the camera angle of the image is mostly vertically downward or inclined to both sides, so the depth of the scene is substantially the same, this will cause the concentration of haze in the image to be approximately the same. Some algorithms that based on the difference between depths or the relative degree of image color attenuation become ineffective. However, the image dehazing algorithm using dark channel prior [7] estimates the concentration of the haze by calculating the minimum value of the RGB color channels within a patch, even if the entire UAV image has the same haze concentration, the medium transmission map can be well estimated. Even so, it cannot well handle the sky area, but the UAV image rarely include sky, so we use dark channel prior to dehaze the UAV image. We use a quad-tree hierarchical searching method to estimate atmospheric light values, this method can effectively avoid the interference of white objects in UAV images on the estimation of the atmospheric light. Moreover, we propose a new regularization optimization formula to refine the medium transmission map, which can make the medium transmission map smoother. Finally, the restored UAV images are obtained using the atmospheric scattering model.

2. Image dehazing

The degradation of image quality in haze weather is mainly caused by the light scattering. Atmospheric scattering model [16] describes the physical properties of light transmitted, hazy image obtained by the imaging equipment can be represented as:

\[
I(x) = J(x)t(x) + A(1-t(x)),
\]

where \(I\) is the observed hazy image, \(J\) is the scene radiance, \(A\) is the global atmospheric light that represents the ambient light in the atmosphere, and \(t(x)\) is the transmission of the reflected light, which is determined by the distance \(d(x)\) between the scene point and the camera:

\[
t(x) = e^{-\beta d(x)},
\]

where \(d\) is imaging distance, and \(\beta\) is the scattering coefficient of the atmosphere. Since the visible light with different wavelength scatter in the same proportion under homogeneous atmosphere conditions, so \(\beta\) commonly assumed to be a constant [17].

In Eq.(1) the first term \(J(x)t(x)\) represents the direct attenuation model. Due to the effect of atmospheric particles’ scattering and absorption, part of the reflected light from the surface of object suffers from scattering or absorption, and the intensity of rest exponentially decreases with the increase of imaging distance. The second term \(A(1-t(x))\) represents the airlight model. Due to the effect of atmospheric particles scattering, the color of the scene has been shifted. With the imaging of spreading distance, the atmospheric light intensity increases gradually.
Figure 1. Block diagram of the UAV image dehazing algorithm.

Figure 1 shows the block diagram of the dehazing algorithm. Firstly, we determine the atmospheric light for an input hazy UAV image. Then, we calculate the scene medium transmission $t(x)$ by the dark channel prior. Moreover, we regularize the scene medium transmission map. Finally, through the atmospheric light and transmission values that have been obtained, we restore the scene radiance $J(x)$ from the input hazy UAV image.

2.1. Atmospheric light estimation

In the literature [7], the brightest pixel value in the 0.1% pixels with largest dark channel values is taken as $A$. However, in such a scheme, the huge objects which are brighter than the atmospheric light may lead to undesirable selection of the atmospheric light. So we adopt a hierarchical searching method based on the quad-tree subdivision [18]. As illustrated in Figure 2, Firstly, the UAV image are divided into four rectangular regions. Calculate the score value for each region, the score value are defined as the average pixel value subtracted by the standard deviation of the pixel values within the region. Then, we select the region with the highest score value, and the region is divide into four smaller regions. Repeat this process until the size of the selected region is smaller than the set threshold $T_s$. Finally, in the final choice of region(Figure 2 red marker region), we calculate the mean of the top 0.1 percent brightest pixels as the atmospheric light.

Figure 2. Atmospheric Light Estimation using quad-tree hierarchical searching method.
2.2. Transmission estimation

In the previous section, we estimated the atmospheric light value. We applied the method of literature [7] to estimate the rough medium transmission map. We first normalize the equation (1) by $A^c$:

$$\frac{I'(x)}{A^c} = \frac{J'(x)}{A^e} t(x) + (1-t(x)).$$

(3)

We assume that the medium transmission $t(x)$ is constant in the local image patch, and the dark channel is obtained on both sides:

$$\min ( \min_{y \in c(x)} I'(x) ) = \min ( \min_{y \in c(x)} J'(x)) \tilde{t}(x) + (1-\tilde{t}(x)),$$

(4)

using the dark channel prior, we can deduce as follows:

$$\min ( \min_{y \in c(x)} J'(x))=0.$$

(5)

By the formula (4) and formula (5), we can calculate the roughly medium transmission:

$$\tilde{t}(x)=1- \min ( \min_{y \in c(x)} I'(x)).$$

(6)

In order to refine the medium transmission map, we need to regularize optimization, before optimization, we make boundary constraints for the medium transmission map:

$$t_{LB}(x)=1- \min_{c \in [R,G,B]} \{I(x) / A^e\},$$

(7)

boundary limit for each pixel:

$$\tilde{t}_{LB}(x) = \max \{\tilde{t}(x), t_{LB}(x)\}.$$

(8)

The estimation in equation (8) is performed in pixels, so it doesn’t produce spatial coherence. In addition to the depth discontinuity, the medium transmission map should be smooth [12], especially for UAV image, it has roughly the same haze concentration. So we smooth the media transmission map by minimize the follows optimization cost function:

$$\sum_{i \in \text{pixels}} E_d(\hat{t}_i) + \lambda E_s(\hat{t}_i),$$

(9)

where $\hat{t}$ is the optimized media transmission, and $\lambda$ are parameters balance the data term and smooth term ($\lambda=50$).

The data term optimization cost function is defined as follows:

$$E_d(\hat{t}_i) = \phi(\hat{t}_i - \tilde{t}_{LB,i}) +\gamma [\phi(\nabla \hat{t}_i - \nabla \tilde{t}_{LB,i}) + \phi(\nabla \tilde{t}_i - \nabla \tilde{t}_{LB,i})],$$

(10)

where $\phi(x) = \sqrt{x^2 + \epsilon}$, $\epsilon=10^{-4}$ is a robust error norm, $\nabla x$ and $\nabla y$ represents the gradient value of the $x$ and $y$ direction of the map, $\gamma$ is the gradient retention weight parameters($\gamma=10$).

The smooth term optimization cost function is defined as follows:

$$E_s(\hat{t}_i) = s_{x,i} \phi(\nabla \hat{t}_i) + s_{y,i} \phi(\nabla \tilde{t}_i),$$

(11)

where $s_{x,i} = (1+e^{\frac{\|\hat{t}_i\|}{0.05}})^{-1}$, $s_{y,i} = (1+e^{\frac{\|\hat{t}_i\|}{0.05}})^{-1}$ is a restriction on the direction of gradient optimization.

We use the iteratively reweighted algorithms [19] to minimize the optimization cost function (9), finally, obtain a smooth media transmission map. Figure 3(c) shows the media transmission map through the optimized. Figure 3(b) is the refined media transmission map by the literature [7]. Obviously, the refine media transmission map becomes smoother through our optimization.

2.3. Recovering the scene radiance

Through the estimation of the atmospheric light and the medium transmission map in the first two sections, we can recover the scene radiation image according to the atmospheric scattering model, as
Figure 3. Transmission Estimation, (a) Haze UAV image, (b) He et al.’s refined transmission map, (c) our refined transmission map.

Figure 4. Comparison of dehaze methods for UAV image, (a) Haze UAV image, (b)(c) He et al.’s results, (d)(e) our results.

\[
\hat{J}(x) = \frac{\{I(x) - [1 - \hat{t}(x)] A\}}{\hat{t}(x)},
\]

where \( \hat{J} \) is the scene radiance, and \( I \) is the haze UAV image. Finally, the haze-free UAV image is recovered.

3. Results

We mainly evaluate the dehazing algorithm through subjective observation. Figure 4 shows the dehazing image obtained the method of He et al. [7] and our improved method. Our experimental subject is the UAV images, we resize the image to the size of 1200×800 pixels. Our experimental platform is Matlab2016a. It can be seen from the dehazed UAV images that the dehazing algorithm of He’s is easy to appear color distortion, and the image’s color in the upper left corner of Figure 4(b)
becomes abnormal, which is caused by the atmospheric light value is underestimation. However, this phenomenon doesn't occur in our algorithm, and the image is more clear. Figure 4(e) is the enlarged image of the red square area in the image of Figure 4(d), and Figure 4(c) is the original article recovered haze-free image. Obviously, the details of the dehazed UAV images by our dehazing algorithm are more clear. And the restoration of the white house area has been improved, which is mainly due to the correctness estimation of the atmospheric light value, as well as in the process of regularization optimization, we refer to the gradient information of the haze UAV image. These fully demonstrate the superiority of our algorithm.

4. Conclusions
In this paper, we propose a dehazing model based on dark channel prior for the UAV image. A quad-tree search method is used to find the best atmospheric light prediction position, thus, the color distortion of the recovered haze-free UAV image is reduced. Moreover, we propose a new regularization optimization scheme to smooth the medium transmission map. The preliminary results show that our dehazing algorithm can effectively recover the clear UAV images.

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