Method for sky region segmentation

Bo Jiang✉, Wan Xu Zhang, Xiao Lei Ma, Yi Ru, Hong Qi Meng and Lin Wang

A new simple and efficient method for sky region segmentation is proposed. The dark channel algorithm used in the field of image haze removal is further developed for sky region segmentation. The proposed method can simply and efficiently achieve image segmentation without any pretreatment which is required in traditional segmentation methods. This method is also conducive to detecting the distant fuzzy scene and suppressing the interference around the segmented object.

Introduction: Image segmentation is the precondition of higher-level processing, e.g. object recognition and feature extraction, and it is the process of differentiating a specific object from other scenes in an image. With the popularity of intelligent visual equipment, a more sophisticated method for image segmentation is becoming increasingly demanded in order to meet practical requirements. More specifically, the sky region segmentation as a subclass of image segmentation has recently attracted extensive attention due to the increasing demand of preciously and efficiently detecting objects in the sky in modern wars.

The existing segmentation methods generally consist of three steps: image preprocessing (e.g. smoothing and filtering), then edge detection and image binarisation are carried out, and the last step is the real image segmentation. However, the aforementioned methods are rather complex due to the difficulty in image preprocessing. More recently, huge progress has been made in the field of image haze removal since the proposal of the dark channel algorithm [1], and then its improved algorithms was proposed subsequently. For example, the corresponding fast algorithm is proposed in [2], and the halo effect is remarkably reduced by template preprocessing in the dark channel calculation in [3]. In this Letter, the dark channel algorithm is applied to sky region segmentation, and a new simple and efficient segmentation method is proposed, which can directly segment the sky region without any preprocessing for the original image.

Sky colour and dark channel principle: On a sunny day, the sky mainly consists of the atmospheric molecules and a small portion of solid particles such as dust. If the diameter of the atmospheric molecules is smaller than the wavelength of visible light, the light scattering intensity is inversely proportional to the wavelength itself. Therefore, the scattering intensity of blue and violet light is the strongest among the visible light. Additionally, the violet light only accounts for a small proportion of the visible light and is less sensitive to human eyes, which leads to the sky colour being blue.

On a foggy day, there is a large quantity of fog droplets suspended in the atmosphere, whose diameter is larger than the wavelength of visible light. In this case the scattering intensity of light with different wavelengths within the visible spectrum is genetally the same, resulting in the white colour of the sky region.

In the field of image haze removal, the McCartney atmospheric physical model used in [1] is widely adopted, and it is defined as

$$I(x) = J(x)t(x) + A(1 - t(x)) \tag{1}$$

where $I(x)$ is the original hazy image, $J(x)$ is the hazy-free image, A is the atmospheric light value, $t(x)$ is the medium transmission, and x is the corresponding pixel. The operation process of the dark channel algorithm [1] for a single image is described as

$$I^{\text{dark}}(x) = \min_{y\in\Omega(x)} \left(\min_{c\in(r,g,b)} I^{c}(y)\right) \tag{2}$$

where $I^{c}(x)$ is one colour channel of $I(x)$, $I^{\text{dark}}(x)$ is the corresponding dark channel image, and $\Omega(x)$ is a template centred at x.

Proposed method: According to the McCartney model, the transmission $t(x)$ is also expressed as

$$t(x) = e^{-\beta d(x)} \tag{3}$$

where β is the scattering coefficient and $d(x)$ is the scene depth. As can be seen from (3), the larger the scene depth $d(x)$ is, the lower the corresponding $t(x)$ will be. If the pixel x_f in $I(x)$ is infinitely distant from the camera, the corresponding $t(x_f) \to 0$. Then

$$I(x_f) = J(x_f)t(x_f) + A(1 - t(x_f)) \to A \tag{4}$$

From (4) above, when the furthest pixel x_f is found in $I(x)$, its pixel value can be taken as the most accurate estimate of A. Note that the average value of x_f in the RGB channels is regarded as A in this Letter. Hence, the key to solving the problem is to find x_f in $I(x)$. The sky region is obviously further from the camera than any other scenes in $I(x)$, so A should be primarily constrained in the sky region.

As there are few reflectors in the sky region, the light that reaches the camera is mainly contributed by the $A(1 - t(x))$ term in this region. The further the pixel is, the higher its value will be. Owing to the highest transmission for x_f, it is the brightest pixel in the sky region. On a sunny day, the light from the sky region is classified as the natural light. According to the RGB colour model, the proportion of the RGB intensity of natural light is close to 1 to 1 to 1. Although the sky is blue under this weather condition, the proportion of RGB intensity in the sky region as a whole can obviously be considered to be balanced compared with the close-range scenes, e.g. red cars and green trees.

In the case of a foggy day, the problem becomes simple. As mentioned above, the scattering intensity of the light with different wavelengths within the visible spectrum is considered to be the same on the whole, thus the brighter the white pixel in the sky region is, the more balanced the proportion of RGB intensity should be.

The sky region with a balanced proportion of RGB intensity can be roughly found after the first operation $\min_{c\in(r,g,b)}(\cdot)$ in (2), but the close-range white objects with the balanced proportion are also selected as the sky region at the same time. Then, after performing the filtering operation $\min_{y\in\Omega(x)}(\cdot)$ in (2), the white objects that are locally incoherent can be excluded ultimately. After the two-step operation above, the brightest pixel in $I^{\text{dark}}(x)$ is exactly the furthest pixel x_f in $I(x)$, and its value can be regarded as the most accurate estimate of A.

To verify how good the proposed method is, we collected test images from the Berkeley Segmentation Dataset and Benchmark, the Internet, and the ones taken by our own in this Letter, and some of them have been adjusted appropriately for display. Figs. 1*a* and *b* show the selected results of x_f on foggy and sunny days, respectively. The position of x_f found first and is marked with blue, and the area of this blue pixel is expanded for display. Sky region segmentation in this Letter is primarily based on A as stated above, and all the positions of pixel values similar to A are labelled as sky region to achieve simple and efficient segmentation. Here, the average intensity of RGB is adopted as a comparison basis. However, there is the possibility that the average intensity of RGB for close-range scene pixels is close to A, and the aforementioned pixels might be selected as the sky region resultantly. To prevent this, the similarity comparison is carried out not only in $I(x)$ but also in $I^{\text{dark}}(x)$.

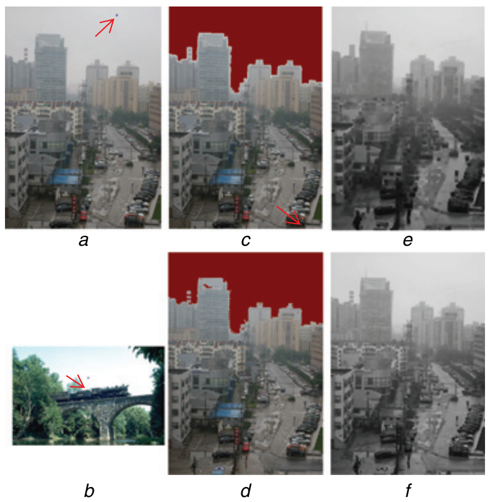

Fig. 1 *Sky region segmentation on foggy and sunny days*

a, b Original images on foggy and fine days , respectively
c, d Segmentation results using 7 × 7, 3 × 3 template, respectively
e, f Transmission with guided-filtering [4] using 7 × 7, 3 × 3 template, respectively

Since the large-scale template plays an essential role in differentiating the distant sky region from the close-range white scenes, the large one is used for selecting A. Moreover, the largest one, the 30×30 template, is employed to find the crucial A. On the other hand, the small-scale template is beneficial to acquire a more elaborate $I^{\mathrm{dark}}(x)$, and thus the small one is employed to improve the comparison accuracy. In brief, we employ the largest-scale template, the 30×30 template, to find the value of A, and then we strike a balance between the large (7×7) and small (3×3) scale templates in the process of calculating similarity in $I^{\mathrm{dark}}(x)$.

With the large 7×7 template, the close-range white scenes can be suppressed effectively as shown in Fig. 1*c*. In this Letter, the selected sky region after the calculation is marked with red. However, it can be seen from Fig. 1*c* that the fitting grade of sky region boundary after segmentation is low when the chosen template scale is large. In comparison, the fitting grade of the sky region obtained using the small 3×3 template is higher, as indicated in Fig. 1*d*; nevertheless, it can also been noticed from Fig. 1*d* that some white scenes with a balanced proportion of RGB intensity, such as the white cars indicated by the red arrow, are wrongly classified as the sky region.

The two dark channel images using the 7×7 and 3×3 templates in the process of calculating similarity in $I^{\mathrm{dark}}(x)$ are illustrated in Figs. 1*e* and *f*, respectively. Obviously, the grade of detail reservation in Fig. 1*f* is higher than that in Fig. 1*e*, so the fitting grade of the sky region boundary after segmentation in Fig. 1*d* is higher than that in Fig. 1*c*. Note that the templates in this Letter except for the one used in finding A have all adopted the guided-filtering [4].

In addition, the proposed method is conducive to detecting the distant fuzzy scene. Fig. 2*a* shows the distant fuzzy mountains indicated by the red arrow, which are hard to distinguish. However, the mountains can be easily detected by this method as illustrated in Fig. 2*b*. A more obvious example is shown in Fig. 2*c*, where a fuzzier tower in the distance is indicated by the red arrow. Although the tower is very difficult to distinguish by the human eye, the proposed method can automatically detect it as shown in Fig. 2*d*. Therefore, our method can potentially be used to assist a computer and the human eye to find the distant fuzzy object. At the same time, this method can avoid missing the tiny sky region as indicated by the red arrow in Fig. 2*d*, so its high performance is validated in terms of the detail aspect.

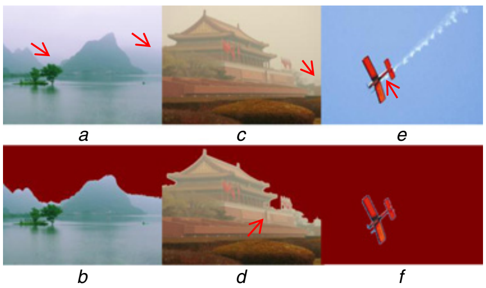

Fig. 2 *Sky region segmentation on special image background*
a, b Original image with fuzzy scene and segmented result, respectively
c, d Original image with fuzzier scene and segmented result, respectively
e, f Original image with interference and segmented result, respectively

The proposed method is also advantageous in effectively suppressing interference around the segmented object. As shown in Fig. 2*e*, the jet contrail is regarded as a strong interference in the process of recognising the jet in the sky, especially at the position indicated by the Red arrow. Fig. 2*f* illustrates that our method can suppress the contrail interference successfully and differentiates the jet from the sky region clearly.

Experimental results: In this Section, we further test the performance of the proposed method using Matlab2010b in a personal computer with an Intel Core i3 processor. As the segmentation method only for the sky region has rarely been reported, we carried out the experiments on the images with different background complexity. Figs. 3*a–c* are the original images with background complexity improving in turn and the experimental results are illustrated in Figs. 3*d–f*. Tiny sky regions are especially difficult to segment, which are indicated by the red arrows as shown in Figs. 3*a–c* and Figs. 3*d–f* illustrate the corresponding segmented results of tiny sky regions. As can be seen, our method is effective for different complexity backgrounds by adjusting the similarity threshold and template scale reasonably.

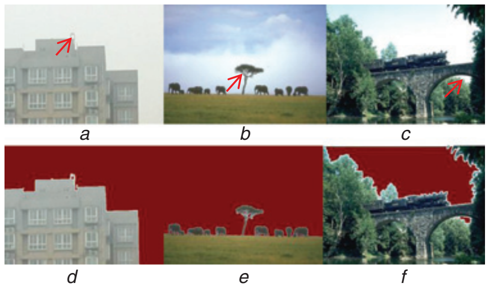

Fig. 3 *Experimental results on different complexity backgrounds*
a–c Original images with background complexity improving in turn
d–f Corresponding segmented results in turn

Conclusion: In this Letter, we report a new simple and efficient method for sky region segmentation, which is based on the combinations of scene depth and the dark channel algorithm. With this method, sky region segmentation for images with different background complexity can be easier and more effectively segmented without any preprocessing compared with the traditional methods, which has been experimentally demonstrated. It is also shown that our method can be employed to detect distant fuzzy scenes and suppress the interference around the object. It should be noted that in the proposed method the similarity threshold needs to be adjusted manually due to the numerous distinctive features between different images. Therefore, it is practically significant to adjust the corresponding parameters automatically, and we leave this problem for future research.

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References

1 He, K., Sun, J., and Tang, X.: 'Single image haze removal using dark channel prior', *IEEE Trans. Pattern Anal. Mach. Intell.*, 2011, **33**, (12), pp. 2341–2353
2 Cheng, F.-C., Lin, C.-H., and Lin, J.-L.: 'Constant time $O(1)$ image fog removal', *Electron. Lett.*, 2012, **48**, (22), pp. 1404–1405
3 Bui, T.M., Tran, H.N., Kim, W., *et al.*: 'Segmenting dark channel prior in single image dehazing', *Electron. Lett.*, 2014, **50**, (7), pp. 516–518
4 He, K., Sun, J., and Tang, X.: 'Guided image filtering', *IEEE Trans. Pattern Anal. Mach. Intell.*, 2013, **35**, (6), pp. 1397–1409