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Dark and Bright Envelopes for Dehazing Images

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Abstract—We present a method for dehazing images. A dark envelope image is derived with the bilateral minimum filter and a bright envelope is derived with the bilateral maximum filter. The ambient light and transmission of the scene are estimated from these two envelope images. An image without haze is reconstructed from the estimated ambient light and transmission.

Keywords—Image dehazing, bilateral minimum filter, bilateral maximum filter, local contrast.

I. Introduction

MANY methods have been presented for dehazing images[1], [2], [3], [4], [5], [6], [7], [8], [9], [10]. For them, the dark channel prior[2] is effective and has been widely used for removing hazes from images. This is an approach for estimating the depth of hazes from a dark channel image which is given by the minimum filter for a minimum channel image.

We propose a dehazing method using upper and lower envelopes of an input image. Firstly, a dark envelope image is yielded by a bilateral minimum filter for an input image, and a bright envelope is derived by a bilateral maximum filter. Next, the ambient light and transmission rate are estimated from these two envelope images. Lastly, The color of the scene with haze removed is restored from the ambient light and transmission rate.

We show by experiments for some hazy images that the proposed method outputs dehazed images of contrast higher than previous methods.

II. Bilateral Minimum/Maximum Filters

Before considering haze removal of color images, we introduce a bilateral minimum and maximum filters used for it. These filters deal with monochromatic images and output pixel values computed by

$$d_{ij} = \frac{\sum_{l=-p}^{p}\sum_{m=-p}^{p} w_{ijlm} c_{i+l,j+m}}{\sum_{l=-p}^{p}\sum_{m=-p}^{p} w_{ijlm}} \tag{1}$$

where c_{ij} is the pixel value in an input image. The bilateral minimum (BiMin) filter is defined with the weight

$$w_{ijlm} = e^{-\alpha c_{i+l,j+m}} \cdot e^{-\beta(l^2+m^2)-\gamma(c_{ij}-c_{i+l,j+m})^2} \tag{2}$$

which outputs a soft minimum of pixel values belonging to the same segment as the central pixel. Changing the sign in the first term in the right hand side of (2) as

$$w_{ijlm} = e^{\alpha c_{i+l,j+m}} \cdot e^{-\beta(l^2+m^2)-\gamma(c_{ij}-c_{i+l,j+m})^2}, \tag{3}$$

we get the bilateral maximum filter which outputs a soft maximum values.

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III. Haze Removal

The color values $I_{ij} = [r_{ij}, g_{ij}, b_{ij}]$ of pixel (i,j) in a hazed image is expressed by

$$I_{ij} = t_{ij} J_{ij} + (1 - t_{ij}) A_{ij} \tag{4}$$

where J_{ij} is a scene color without hazes, A_{ij} is the color of ambient light and t_{ij} is a transmission rate of the haze (as will be shown below, $t_{ij} > 0$ in our method). If t_{ij} and A_{ij} are known, we can get J_{ij} from eq.(4) as

$$J_{ij} = (I_{ij} - A_{ij})/t_{ij} + A_{ij}. \tag{5}$$

A. Dark/Bright Envelope Images

Our procedure starts from the minimum channel

$$c_{ij} = \min\{r_{ij}, g_{ij}, b_{ij}\} \tag{6}$$

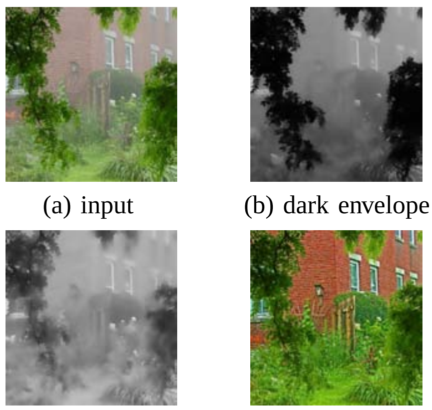
and the maximum channel

$$c'_{ij} = \max\{r_{ij}, g_{ij}, b_{ij}\}. \tag{7}$$

The BiMin filter is applied to the minimum channel for yielding a dark envelope of an input image, and the BiMax filter is applied to the maximum channel for deriving a bright envelope image.

B. Estimation of Ambient Light

We assume the ambient light is gray: $A_{ij} = [B_{ij}, B_{ij}, B_{ij}]$ where B_{ij} is the pixel value of the bright envelope.



(a) input (b) dark envelope (c) bright envelope (d) output

Fig. 1. Example image.

C. Estimation of Transmission Rate

Taking the minimum of r, g, b in the both side of (4), we get

$$\min_{r,g,b} I_{ij} (= c_{ij}) = t_{ij} \min_{r,g,b} J_{ij} + (1 - t_{ij}) A_{ij} \qquad (8)$$

The dark channel prior[2] assumes $\min_{r,g,b} J_{ij} = 0$ by which eq.(8) is simplified to $c_{ij} = (1 - t_{ij}) A_{ij}$. Substituting $A_{ij} = [B_{ij}, B_{ij}, B_{ij}]$ into this expression leads to $t_{ij} = 1 - c_{ij}/B_{ij}$. Applying the BiMin filter to this, we get $t_{ij} = 1 - D_{ij}/B_{ij}$ where D_{ij} is the pixel value of the dark envelope. This is our estimation of the transmission rate, however this t_{ij} leads to perfect removal of hazes yielding unnatural images with flat depth. Therefore we multiply $0 < \delta \leq 1$ as

$$t_{ij} = 1 - \delta D_{ij}/B_{ij} \qquad (9)$$

for retaining hazes slightly (in the experiments below, we set $\delta = 0.9$ from which $t_{ij} \geq 0.1$).

The dark envelope D_{ij} of the image in Fig.1(a) is shown in Fig.1(b) and the bright envelope is shown in Fig.1(c).

D. Estimation of Scene Color J_{ij}

Substituting the above eq.(9) and $A_{ij} = [B_{ij}, B_{ij}, B_{ij}]$ into (5), we get

$$J_{ij} = (I_{ij} - A_{ij})/(1 - \delta D_{ij}/B_{ij}) + A_{ij} \qquad (10)$$

which is outputted as a dehazed result.

An output from Fig.1(a) is shown in Fig.1(d) where we set $p = 5, \alpha = 0.01, \beta = 0.01, \gamma = 0.001$, and δ is 0.9 in (9). Other example images are shown in Fig.2

IV. Experiments

The results of our method are compared with those by Tarel et al.[9] and He et al.[2] which are representative previous methods. In addition to the image "yard" in Fig.1(a), we experimented for images in Fig.2 and compared the local contrast

$$c = \frac{1}{n} \sum_{i=1}^{n} \frac{\max_i - \min_i}{\max_i + \min_i} \qquad (11)$$

where $\max_i$ is the maximal luminance in the i-th 3×3 patch and $\min_i$ is the minimum luminance, n is the total number of patches. The values of c of outputted images are shown in table I where "ya" is yard, "tr" is train, "ro" is road, "pu" is pumpkins, "co" is cones, "st" is stadium, "mo" is mountain, and "ny" is New York. The contrast of our method is higher than the methods by Taral et al. [9] and He et al. [2].

TABLE I
Comparison of contrast with Tarel et al.[9] and He et al.[2]

	ya	tr	ro	pu	co	st	mo	ny
Tarel	0.47	0.15	0.13	0.33	0.30	0.35	0.28	0.17
He	0.31	0.17	0.18	0.33	0.30	0.40	0.20	0.33
ours	0.48	0.37	0.33	0.47	0.46	0.48	0.40	0.49

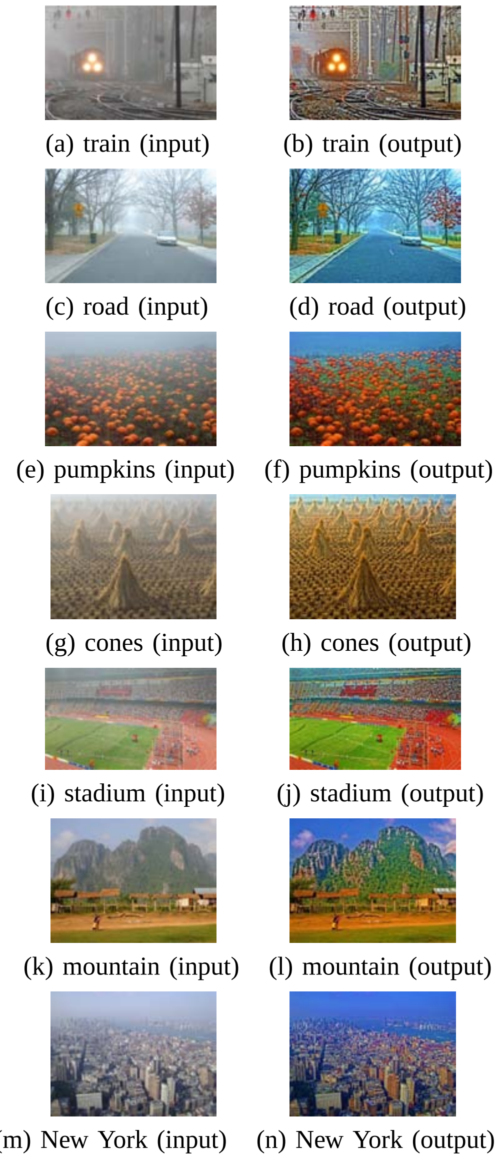


Fig. 2. Experimented images.

V. Conclusion

We have proposed an image dehazing method using the bilateral minimum and maximum filters and have shown by experiments that our method outputs images with high contrast. Extension of this method to general image enhancement except for image dehazing is under study.

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