HAZE REMOVAL WITHOUT TRANSMISSION MAP REFINEMENT BASED ON DUAL DARK CHANNELS

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Abstract

Single image haze removal has been a challenge in the field of image processing. In [1], a haze removal scheme based on dark channel prior (DCP) is presented and is getting popular because of its satisfactory performance for most of cases. However, it is known that the scheme proposed in [1] suffers from two problems: high computational cost and over-exposure when a bright area shown in images. This paper proposes a dehazing algorithm with dual dark channels where the soft matting to refine the transmission map is avoided and the atmospheric light is estimated directly from a dark channel. The objective of proposed dehazing algorithm (PDA) is to alleviate or remove the two problems found in [1]. Several examples are given to verify the PDA and to compare it with the DCP scheme. The simulation results show that the PDA is about 2.5 times, on average, faster than the DCP since the soft matting is avoided. Similar visual quality to the DCP is found in the PDA which is of better color situation and without over-exposure problem as in the DCP scheme.

Keywords:
Haze removal; Dark channel prior; Soft matting; Transmission refinement

1. Introduction

As imaging devices, CCD and CMOS, have been widely applied to surveillance systems and consumer electronic appliances, the demand on image quality is getting more critical. It is known that the image quality heavily depends on the imaging environment when an image was taken. Haze, which degrades the image quality, is traditionally an atmospheric phenomenon where particles obscure the clarity of the sky. Fog and smoke are of similar phenomena to haze. Thus, in this paper we use the term “haze” to include fog and smoke. Haze removal may help in many image-based applications where visibility is an important issue. Recently, several model-based schemes have been reported for single image haze removal or dehazing. The challenge is to appropriately estimate the model parameters, such as atmospheric light and transmission map. In [2], the transmission and surface shading are assumed locally uncorrelated under which the albedo of the scene and the transmission are estimated. The dehazing performance heavily depends on the assumption in [2]. That is, a dehazing result is satisfied if the local uncorrelation assumption is appropriate and vice versa. In [3], dehazing problem was considered as a contrast enhancement problem. By the observation which an image with haze is of higher contrast than that in a hazy image, an approach to maximize local contrast was proposed. However, the restored image may look unnatural because of local contrast maximization. In 2011, a popular single image dehazing scheme was proposed based on dark channel prior [1]. In [1], an interesting statistics is observed which is called dark channel prior (DCP). The prior is found that some pixels are very often have very low values in at least one color channel, for a non-sky local region in outdoors haze-free images. The DCP-based scheme in [1] works well in general. However, the DCP dehazing scheme suffers from high computational cost and over-exposure. Many variations of the DCP scheme have been reported. Some of them are in [4-7]. This paper attempts to tackle the problems simultaneously. The organization of this paper is in the followings: Section 2 briefly reviews the DCP scheme in [1]. Based on the DCP scheme, in Section 3 an approach is presented to improve the performance of DCP scheme. In Section 4, examples are provided to demonstrate the performance of the proposed approach. Conclusions are included in Section 5.

2. Review of the DCP scheme

Based on the dark channel prior (DCP), a dehazing algorithm is developed in [He] which will be abbreviated as DCP scheme in this paper. In the DCP scheme, the following haze model is assumed.
\( J(x) = J(x) \cdot t(x) + A[1 - t(x)] \) \hspace{1cm} (1)\n
where \( I(x) \) denotes the observed intensity, \( J(x) \) the scene radiance, \( A \) the global atmospheric light, and \( t(x) \) the transmission map. With the model (1), the implementation steps of DCP scheme are summarized as follows:

**Step 1.** Calculate the dark channel though the minimum filter as

\[ J_{\text{dark}}(x) = \min \{ \min_{y \in \Omega(x)} (I'(y)) \} \] \hspace{1cm} (2)\n
where \( I'(y) \) is one of three components \{r, g, b\} in the input image and \( \Omega(x) \) is a window centered at \( x \).

**Step 2.** Estimate the transmission map as

\[ \tilde{t}(x) = 1 - \omega \times J_{\text{dark}}(x) \] \hspace{1cm} (3)\n
where \( \omega \) is a scaling factor.

**Step 3.** Obtain the refined \( \tilde{t}(x) \), \( t(x) \), by the soft matting.

**Step 4.** Estimate the global atmospheric light \( A \) by tracking back from 0.1% maxima of \( J_{\text{dark}}(x) \) to the maximum of the corresponding pixels in the input image.

**Step 5.** Recover the scene radiance as

\[ \hat{J}(x) = \frac{I(x) - A}{\max\{t(x), t_0\}} + A \] \hspace{1cm} (4)\n
where \( t_0 \) is a user-defined lower bound of \( t(x) \).

The flowchart of DCT scheme is shown in Figure 1. In general, the DCP scheme has satisfactory dehazing results. However, two problems are found in the DCP scheme. First, soft matting results in high computational cost. Second, over-exposure may happen in dehazed images when sky or bright area is presented in the original image. An example “Lane” shows the problem of over-exposure as marked in Figure 2.

3. **The Proposed Approach**

The objectives of the paper are: (i) to avoid the soft matting and consequently to reduce the computational cost, and (ii) to relieve the over-exposure problem found in the DCP scheme. The motivation and the proposed approach are presented in Section 3.1 and Section 3.2, respectively.

3.1. **Motivation**

Note that the soft matting is used to refine the transmission map. When observing transmission maps with different window sizes, we find a clue to avoid the soft matting. If \( 1 \times 1 \) minimum filter is used to estimate the transmission map, no refinement is required at all. Moreover, note that in [1] \( 15 \times 15 \) minimum filter is good for the estimation of dark channel prior. Thus, dual dark channels are found by the minimum filters with \( 1 \times 1 \) and \( 15 \times 15 \) windows, respectively. The two dark channels, \( J_{15\text{dark}}(x) \) and \( J_{15\text{dark}}(x) \), are used to estimate the transmission maps \( t_f(x) \) and \( t_s(x) \), respectively. The final estimated transmission map \( t_f(x) \) is obtained by linearly combining \( t_f(x) \) and \( t_s(x) \).

As for the atmospheric light \( A \), we find that it can be estimated directly by dark channel \( J_{15\text{dark}}(x) \), since they are correlated. In the light of ideas described above, the proposed dehazing algorithm based on dual dark channels...
is introduced in the following section where transmission map refinement is avoided.

### 3.2. The proposed dehazing algorithm

According to the motivation in Section 3.1, a single image dehazing algorithm (PDA) is proposed where (i) dual dark channels \( J_{1\text{dark}}(x) \) and \( J_{15\text{dark}}(x) \) are found by 1\( \times \)1 and 15\( \times \)15 minimum filters, (ii) the soft matting to refine transmission map in [1] is avoided, (iii) the atmospheric light \( A \) is directly estimated by \( J_{15\text{dark}}(x) \), and (iv) the final transmission map \( t_f(x) \) is obtained through dual dark channels. The implementation steps of the PDA are described in the following.

**Step 1.** Calculate the dark channel and transmission map with 1\( \times \)1 window, \( J_{1\text{dark}}(x) \) and \( t_1(x) \), as

\[
J_{1\text{dark}}(x) = \min_{y \in 15\text{dark}}(I'(y))
\]

\[
t_1(x) = 1 - \omega_{1} \times J_{1\text{dark}}(x)
\]

where \( \omega_{1} \) is a scaling factor.

**Step 2.** Calculate the dark channel and transmission map with 15\( \times \)15 window, \( J_{15\text{dark}}(x) \) and \( t_{15}(x) \), as

\[
J_{15\text{dark}}(x) = \min_{y \in 15\text{dark}}(I'(y))
\]

\[
t_{15}(x) = 1 - \omega_{15} \times J_{15\text{dark}}(x)
\]

where \( \omega_{15} \) is a scaling factor.

**Step 3.** Estimate atmospheric light \( A \) through \( J_{1\text{dark}}(x) \) as

\[
A = \alpha \times \max[J_{1\text{dark}}(x)]
\]

where \( 0 < \alpha \leq 1 \) is a scaling factor.

**Step 4.** Estimate the final transmission map as

\[
t_f(x) = \beta \times t_1(x) + (1 - \beta) t_{15}(x)
\]

where \( 0 < \beta \leq 1 \) is a user-defined constant.

**Step 5.** Recover the scene radiance as

\[
J(x) = \frac{I(x) - A}{\max[t_f(x), t_0]} + A
\]

where \( t_0 \) is a user-defined lower bound of \( t_f(x) \).

The flowchart of the PDA is depicted in Figure 3.

### 4. Simulation Results

In this section, four images, Sakura, Lane, Garden, and Forest, are provided to verify the PDA which is then compared with the DCP scheme. By MATLAB, the PDA is programmed where the parameters are set as \( \omega_{1} = 0.75 \), \( \omega_{15} = 1 \), \( \alpha = 0.95 \), \( \beta = 0.85 \), and \( t_0 = 0.1 \). Moreover, the MATLAB code available on the website [8] is implemented for the DCP scheme.

The first example is image Sakura whose original image is shown in Figure 4(a) and the corresponding dehazed images by the DCP and the PDA are given in Figures 4(b) and 4(c), respectively, where the processing times for dehazed images are shown as well. As expected, the processing time, \( t_p \), of the PDA is 3.03 times faster than the DCP scheme since the soft matting is avoided in the PDA. Moreover, the dehazed Sakura by the PDA is of similar visual quality with better color saturation as shown in Figures 4(b) and 4(c).

The second example is the image Lane. The original...
image Lane is shown in Figure 5(a) and the corresponding dehazed images by the DCP and the PDA are shown in Figures 5(b) and 5(c), respectively. In image Lane, the processing time of PDA is about 2.44 times faster than the DCP as marked in Figures 5(b) and 5(c). As for the visual quality, the dehazed image after the PDA is superior to the DCP and the color is more saturated for the PDA. Moreover, the problem of over-exposure is found in the DCP as in Figure 5(b) while the problem is relieved in the PDA as shown in Figure 5(c).

![Figure 5. Image Lane (a) original (b) after the DCP (t_p = 77.178s) (c) after the PDA (t_p = 31.698s)](image)

As the third example, the original Garden is shown in Figure 6(a) while the dehazed images obtained from the DCP and PDA are given in Figures 6(b) and 6(c), respectively. In this example, the PDA is 2.63 times faster than the DCP. Similar visual quality and better color saturation can be found as in the two previous examples. It should be noted that the haze-like image Garden in Figure 6(a) is not a real hazy image but is caused by the window filtering effect on the light. It suggests that the DCP or the PDA can be applied to enhance the visual quality of haze-like images.

![Figure 6. Image Garden (a) original (b) after the DCP (t_p = 97.308s) (c) after the PDA (t_p = 36.988s)](image)

The final example is image Forest which is shown in Figure 7(a) and its corresponding dehazed images are given in Figure 7(b) and 7(c), respectively. As before, the PDA is 2.60 times faster than the DCP. Similar visual quality to the DCP is found for the PDA and better color saturation is for the PDA. However, halos happen in depth discontinuities in the dehazed Forest by the PDA as marked in Figure 7(c). It suggests that the PDA needs improved to get rid of the problem of halos.
5. Conclusion

This paper presented a single image dehazing algorithm where dual dark channels were employed and the soft matting is avoided. The proposed dehazing algorithm (PDA) attempted to reduce the computational cost in [1] and to relieve the problem of over-exposure in dehazed images. Four images were considered to justify the PDA and the results showed that the PDA works about 2.5 times, on average, faster than the DCP scheme while remains similar visual quality and better color saturation. However, halos happened in depth discontinuities in the Forest example. In further research, the halo problem will be tackled such that the PDA may be made more practical in the related applications.

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References