Remote Sensing Image Dehazing using Guided Filter

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Abstract: *Remote sensing image dehazing is challenging because it is massively ill-posed and the haze is dependent on the unknown depth information. Haze removal based on dark channel prior is effective, and refining the transmission map with Gaussian filter will produce a god result. But need to improve the naturalness and sharpness and effectiveness of images and to remove fine haze . So Proposes new approach to dehaze the remote sensing image using guided filter. Guided filter is a type of edge-preserving smoothing operator, which filters the input image under the guidance of another image. Experiments and comparisons show that this method generates satisfactory dehazed results with improved naturalness and sharpness.*

Keywords: *Guided Filter, Remote Sensing, Image Dehazing*

1. INTRODUCTION

Remote sensing images have been widely used in various fields including agriculture, forestry, hydrology, and military. Widespread use of remote sensing images is predicated on high-quality images. However, remote sensing is usually vulnerable to weather effects. In general, remote sensing images are taken at a considerable distance from the earth's surface. Consequently, electromagnetic energy cannot reach the sensor before it passes through a substantial atmospheric path. During propagation, the incoming energy interacts with the atmosphere. Some atmospheric effects, such as haze, fog, smoke and cloud, degrade the quality of the received images. In this letter, we address remote sensing images degraded by haze. Images taken under haze conditions often lack visual vividness and appeal, and moreover, they are characterized by a poor visibility of the scene. Guided filter is a novel explicit image filter. The filtering output is locally a linear transform of the guidance image. On one hand, the guided filter has good edge-preserving smoothing properties like the bilateral filter, but it does not suffer from the gradient reversal artifacts. On the other hand, the guided filter can be used beyond smoothing: With the help of the guidance image, it can make the filtering output more structured and less smoothed than the input. Demonstrate that the guided filter performs very well in a great variety of applications, including image smoothing/enhancement, HDR compression, flash/no-flash imaging, matting/feathering, dehazing, and joint up sampling. Moreover, the guided filter naturally has an O(N) time (in the number of pixels N) 1 no approximate algorithm for both gray-scale and high dimensional images, regardless of the kernel size and the intensity range.

In recent years, increasing attention has been paid to development of methods that remove haze from remote sensing images. As a result, a number of scene-based algorithms are available to remove haze from the visible bands. Richter proposed a haze removal algorithm using a haze/clear transition region. Du *et al.* removed the haze using a wavelet transform analysis technique. Zhang *et al.* developed a haze optimized transformation (HOT) to detect and remove the haze region from Landsat TM/ETM+ archives. Moroand Halounova removed haze region successfully from IKNO Simageries based on an improved haze removal algorithm .In the present years, haze removal is performed on the basis of the method, which is dark channel prior, originally proposed by He *et al.*. On the basis of the dark channel prior, we propose a simple but effective method for haze removal. Uses soft matting method to refine the transmission, refine the atmospheric veil with a lowpass Gaussian filter. In order to eliminate the color distortion and oversaturated areas in the restored images, we recomputed the transmission, after that to improve the sharpness; visual vividness and naturalness enhance the image using a guided filter. This can achieve good results and sufficient speed.

In this letter, present a fast and physical-based method for single remote sensing image dehazing and enhance the image using guided filter. It will be shown that restored images are consistent with the original images and visually appealing. The remaining letter is organized as follows. In Section I, a brief analysis of haze imaging model is introduced. In Section II, a detailed description of algorithm is given. In Section III, experimental results and a comparison with are shown. Finally, conclusions are drawn in Section V.

2. PROPOSED SYSTEM OVERVIEW

2.1. Dark Channel Prior

The core of haze removal for an image is to estimate the airlight and transmission map. Assuming the airlight is already known, to recover the haze free image. The dark channel prior, which was discovered by K. He, J. Sun, and X. Tang, is based on the following observation of outdoor haze-free images: In most of the nonsky patches, pixels in at least one color channel (r, g, or b) have a low intensity value and are eve n close to zero. For an image $\mathbf{J}$, we define its dark channel $\mathbf{j}^{dark}$ as

$$\mathbf{J}^{dark}(x) = \min_{y \epsilon \Omega(x)} \left(\min_{c \epsilon \{r, g, b\}} \mathbf{J}^{C}(y) \right)$$

Where $\mathbf{J}^{C}$ is a color channel of $\mathbf{J}$ and $\Omega(x)$ is a local patch centered at $\mathbf{x}$. According to dark channel prior, for an outdoor haze-free image $\mathbf{J}$, the intensity of its dark channel image $\mathbf{J}^{dark}$ is very low and close to zero except for the sky region. To verify how good the dark channel prior is on remote sensing images,

2.2. Estimate the Atmospheric Light and Coarse Veil

First choose the top 0.1% brightest pixels in the dark channel as the most haze-opaque region. Then the value of A_∞ is extracted from the original hazy image from the same location as its dark channel image; the brightest pixel in the original image $\mathbf{I}$ is considered as the global atmospheric light. This approach is more reliable than only searching for the single brightest pixel in the entire image.

After estimating the global atmospheric light A_∞ then defines the atmospheric veil $\mathbf{V}(\mathbf{x})$ as follows:

$$v(x) = 1 - t(x)$$

Obviously, the transmission $\mathbf{t}(\mathbf{x}) = e^{-\beta d(x)}$ is within (0, 1). Therefore, the atmospheric veil $\mathbf{V}(\mathbf{x})$ is also within the (0, 1) interval. The atmospheric veil presents the additive airlight to the scene imaging, and moreover, it is an increasing function with the distance $d(\mathbf{x})$ from the object to the observer. So the haze imaging model can be rewritten as

$$I(x) = J(x).t(x) + A_\infty v(x)$$

Compute the minimum color channel, which aims at preserving a maximum amount of detail, to get the coarse atmospheric veil, which is

$$\overline{V}(x) = \left(\min_{c \in [r, g, b]} \frac{I^c(x)}{A_\infty^c} \right)$$

2.3. Refine the Atmospheric Veil using Gaussian

A low-pass Gaussian filters to refine the atmospheric veil. Gaussian filter is a nonlinear filter that can smooth images. Then smooth the atmospheric veil using a lowpass Gaussian filter, and the refined atmospheric veil $\mathbf{V}(\mathbf{x})$ can be expressed as

$V(x) = \frac{1}{W_g} \sum_{y \in s} G_\sigma (||x - y||) \overline{V}(x)$

Where Wg is the sum weight of the local patch centered at pixel $\mathbf{x}$

$w_g = \sum_{y \in s} G_\sigma (||x - y||)$

Here G is a Gaussian function

$$G_\sigma(\text{x}) = e^{\frac{-x^2}{2\sigma^2}}$$

And the parameter σ represents the size of the neighborhood used to smooth a pixel. A large σ will smooth more, that is, it combines values from more distant image locations. We fix it to 2 for all results in this letter. According to the lowpass Gaussian filter, those pixels closer to the centered pixel **x** will get larger weights.

With the refined atmospheric veil, the transmission can be easily calculated according to

$$v(\text{x}) = 1 - t(\text{x})$$

2.4. Recover the Haze-Free Image

In order to eliminate the color distortion, redefine the transmission **t(x)**. First, compute the difference between the color channel of the image $\frac{\mathbf{I}_\infty}{\mathbf{A}_\infty}$ and the global atmospheric light $\mathbf{A}_\infty$, and threshold it using a predefined value M. If the difference is smaller than M, we recomputed the transmission

$t'(\text{x}) = \min (\max (M/|I(\text{x})/ \; \mathbf{A}_\infty - \mathbf{A}_\infty|, 1).t(\text{x}),1)$

Where **t(x)** is the refined transmission and the threshold M is obtained experimentally. A brighter pixel will get higher transmission. For remote sensing images in this letter, test the threshold M from 0 to 200 with the step size of 5. It turns out that 125 are good enough for images plagued by constant haze level in our letter. However, for different remote sensing images with varying degrees of haze effect, the threshold may be different.

Then the atmospheric veil is

$$V'(\text{x}) = 1\text{-}\, t'(\text{x})$$

For bright regions the intensity of the pixels is larger than that of the global atmospheric light, and their corresponding transmission is high. Actually, this phenomenon is caused by our recomputed transmission. The transmission of the bright regions whose intensity is close to the global atmospheric light will get large value. The bottom right image of Fig. 3 shows the histogram of our refined transmission, from which we can see that the value of the refined transmission mostly ranges from 0.4 to 0.8. Moreover, the intensity of more than 98 percent of the pixels in the transmission is between 0.4 and 0.9, which is consistent with the physical atmospheric transmittance.

Then the final scene radiance **J(x)** can be easily restored by

$$J(\text{x}) = \; A_\infty \; \text{x} \; \frac{I(\text{x})/_{A_\infty} - KV'(\text{x})}{t'(\text{x})}$$

2.5. Guided Filter

Define a general linear translation-variant filtering process, which involves a guidance image I, a filtering input image p, and an output image q. Both I and p are given beforehand according to the application, and they can be identical. The filtering output at a pixel i is expressed as a weighted average:

$$q_i = \sum_j W_{ij}(I)p_j$$

Where i and j are pixel indexes. The filter kernel W_{ij} is a function of the guidance image I and independent of p. This filter is linear with respect to p.

2.5.1. Definition

Now define the guided filter. The key assumption of the guided filter is a local linear model between the guidance I and the filtering output q. We assume that q is a linear transform of I in a window w_k centered at the pixel k:

$$q_i = \; a_k I_i + \; b_k, \forall \in \; w_k$$

Where (a_k, b_k) are some linear coefficients assumed to be constant in w_k. We use a square window of a radius r. This local linear model ensures that q has an edge only if I has an edge, because $\nabla_q = a\nabla.I$. This model has been proven useful in image super-resolution, image matting, and dehazing. To determine the linear coefficients (a_k, b_k) we need constraints from the filtering input p.We model the output q as the input p subtracting some unwanted components n like noise/textures:

$$q_i = p_i - n_i$$

Then seek a solution that minimizes the difference between q and p while maintaining the linear model. Specifically, we minimize the following cost function in the window w_k.

$$E(a_k, b_k) = \sum_{i\varepsilon\, w_k} ((\, a_k I_i + b_k - p_i)^2 + \epsilon\, b_k{}^2)$$

Here, ϵ is a regularization parameter penalizing large a_k. The linear ridge regression model and its solution is given by

$$a_k = \frac{\frac{1}{|w|}\sum_{i\varepsilon w_k} I_i\, p_i - \mu_k \bar{p}_k}{\sigma_k^2 + \epsilon}$$

$$b_k = \bar{p}_k - b_k\, \mu_k$$

Here, μ_k and σ_k^2 are the mean and variance of I in w_k, |w| the number of pixels in w_k, and $\bar{p}_k = \frac{1}{w}\sum_{i\varepsilon w_k} p_i$ is the mean of p in w_k. Having obtained the linear coefficients (a_k, b_k) we can compute the filtering output q_i.
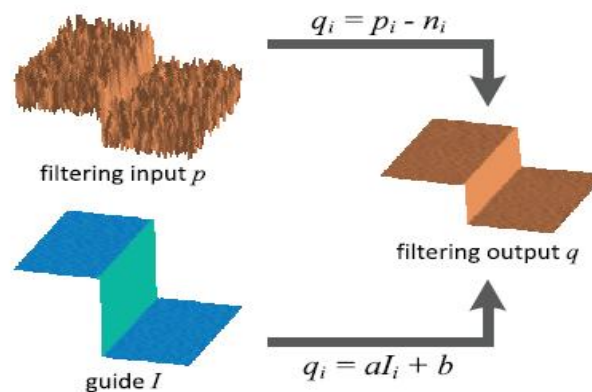
Fig1. *Shows an illustration of the guided filtering process.*

However, a pixel i is involved in all the overlapping windows w_k that covers i, so the value of q_i. is not identical when it is computed in different windows. A simple strategy is to average all the possible values of q_i. So after computing (a_k, b_k) for all windows w_k. Compute the filtering output by

$$q_i = \frac{1}{w}\sum_{K|i\varepsilon w_k} (a_k I_i + b_k)$$

Noticing that $\sum_{k|i\varepsilon w_i} a_k = \sum_{k\varepsilon w_i} a_k$ due to the symmetry of the box window, we rewrite the above equation

$$q_i = \bar{a}_i I_i + \bar{b}_i$$

Where $\bar{a}_i = \frac{1}{|w|}\sum_{k\varepsilon w_i} a_k$ and $\bar{b}_i = \frac{1}{|w|}\sum_{k\varepsilon w_i} b_k$ are the average coefficients of all windows overlapping i

Algorithm1. *Guided Filter*

Input: filtering input image p, guidance image I, radius r, regularization ϵ

Output: filtering output q.

1. $mean_I = F_{mean}(I)$

   $mean_P = F_{mean}(P)$

   $corr_I = F_{mean}(I.* I)$

   $corr_{IP} = F_{mean}(I. * P)$

2. $varr_I = corr_I - mean_I.* mean_I$

   $corr_{IP} = corr_{IP} - mean_I.* mean_P$

3. $a = corr_{IP}./(var_I + \epsilon$

   $b = mean_P - a.* mean_I$

4. $mean_a = F_{mean}(a)$

   $mean_a = F_{mean}(p)$

3. $q = mean_a.* + mean_b$

4. EXPERIMENTAL RESULTS

To demonstrate the effectiveness of our algorithm, we manually pick out several remote sensing images and do experiments on these hazy images. For an image of size 600×400 pixels, it takes 0.736s to process on a PC with a 3.2 GHz Intel Core i3 Processor using MATLAB 2010a. And the recovered image is visually appealing.
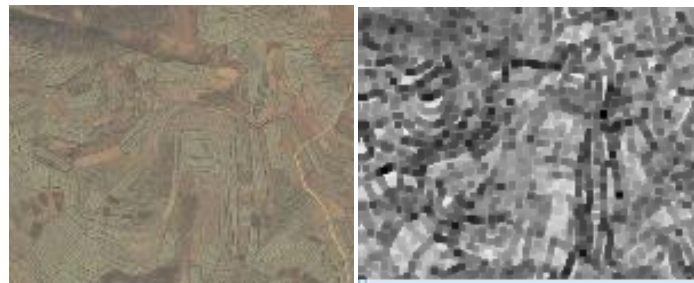
(a) *Input haze image*   (b) *Dark channel prior*

Fig2. *Shows the dark channel of the haze image.*

(a) *Atmospheric veil*   (b) *Transmission map*

Fig3. *Shows the atmospheric veil and its transmission map.*

(a) Input haze image   (b) Dehazed image

Fig4. *Shows the dehazed image.*

Fig5. *Shows the enhanced image.*

Above figure shows that dehazed image is enhanced using duided filter.By observing this picture we can say that sharpness, naturalness and visual vividness of the image is improved and retained the very fine details and preserved the color of the original scene and most importantly fine haze from the dehazed image is removed.

5. CONCLUSIONS

It is a simple, but effective, method for remote sensing image Haze removal. This dehazing technique worked well without producing halo artifacts and was very fast. Based on the dark channel prior, automatically extract the global atmospheric light and roughly estimate the atmospheric veil. We then refined the atmospheric veil using a low-pass Gaussian filter. In order to eliminate the color distortion of the recovered image, then recomputed the transmission. Haze-free image can be obtained by the global atmospheric light and the transmission. To improve the visual vividness, naturalness and sharpness of the image and to remove more fine haze use a guided filter. It will generate satisfactory dehazed results with improved naturalness and sharpness. Simulate experiments to validate the algorithm. Remote sensing images recovered were visually appealing, which retained the very fine details and preserved the color of the original scene with low processing time. By using the guided filter it will preserve all the edges and fine haze are also removed. Moreover, for images containing partly clear and partly hazy areas, algorithm can achieve good results.

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