DUAL DOMAIN METHOD FOR SINGLE IMAGE DEHAZING AND ENHANCING

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ABSTRACT

In this paper, we propose a novel method for improving the visibility of an image (with fog or haze), as well as the image’s details. The proposed method adjusts the global contrast in the spatial domain for dehazing fog or haze spread over images and then enhances the local contrast in the transform domain for reviving the details of images. Compared to the previous methods performing in the spatial domain only, the proposed method improves the visibility and quality of images significantly.

Index Terms— Dehazing, Local contrast enhancement

1. INTRODUCTION

Improving the quality of foggy or hazed image falls into two broad categories: 1) adjusting contrast related to visibility of the image, 2) enhancing local contrast representing details of the image. For improving visibility of a foggy image, dehazing methods exist for grayscale and color images [1, 2, 3, 4, 5]. The dehazing methods perform in the spatial domain for increasing the image contrast. However, the spatial domain adjustment of the image contrast often degrades the details within the image because the contrast adjustment in spatial domain can control the global contrast variation but can not take local contrast variations into account. To reduce the loss of details, we propose a method to dehaze fog or smog in the spatial domain first and then enhance the local contrast in the transform domain.

In the spatial domain, removing haze is based on a model of atmospheric scattering which tries to recover the original scene as if haze wasn’t present. This is achieved by using the atmospheric dichromatic equation [6] that models over-the-horizon scattering. With this model, there is one equation and three unknowns: airlight, transmission, and the non-hazy image. The amount of haze observed is a function of transmission, \( t \), which itself is a function of distance of the radiant objects and size of the scattering particles. The transmission, or some form of it, must be obtained to remove haze in addition to the airlight color \( \mathbf{a} \). The airlight \( \mathbf{a} \) can be estimated in several different ways and are discussed in [2, 3, 4, 5, 6].

In order to estimate \( t \), prior intuition is used to generate a rough estimate where most methods require a large amount of complexity to generate a good estimate. The complexity in [1, 2, 3] arise from refining the estimate of \( t \) due to memory requirements and amount of time needed to refine \( t \). The method proposed in [1] aggressively enforces local contrast by assuming airlight color variations are smooth which requires huge complexity. Both methods in [2] and [3] use large sparse matrices to represent a raw estimate where in [2] a Gauss Markov random field smoothing operation is used and the algorithm in [3] uses a spectral matting method for refining \( t \).

On the other hand, [4] and [5] do not require a large amount of memory or complexity in estimating \( t \). The Median Dark Channel Prior (MDCP) [5] is fast and simple to implement since it reduces the size of kernel used by the filter estimating \( t \) and uses a median filter. Therefore, we use it as a preprocessor step. At cost of gaining speed and lowering complexity, the MDCP method will not accurately estimate \( t \) due to color of objects being close to \( a \) and strong texture and details in a scene (except occlusion edges) which are difficult to completely smooth out unless a very large kernel is used. In addition, the MDCP method is specifically designed for removing haze which degrades details of images.

In order to recover the details degraded during dehazing, we propose a novel method for enhancing the local contrast in the transform domain. Conventional local contrast enhancement methods in the transform domain define the contrast measure using frequency bands and then adjust the local contrast with respect to the measurement [7, 8]. Even though these methods are less sensitive to images and require relatively low complexity, they often cause blocking artifacts between transform blocks because average pixel values of blocks are modified. Moreover, there could be significant ringing artifacts around edges because these methods increase contrast in all directions without considering edge direction.

Unlike the conventional methods, the proposed method avoids blocking artifacts by modifying the overall frequency components taking into account the Human Visual System (HVS) while maintaining the low frequency components. The proposed method also significantly reduces ringing artifact by increasing the local contrast along edge directions. Moreover, the proposed method adjusts the local contrast in each frequency component, whereas the conventional methods adjust the contrast in frequency bands. Consequently, the enhancement performance of the proposed method yields high-quality images and is more robust compared to the conventional methods.

Experiment results verified that the proposed dual domain method significantly improves the image quality (texture, details and color) of dehazed images. Section 2 presents the dehazing method using Median Dark Channel Prior (MDCP) where Section 3 presents the local contrast enhancement algorithm. The experiment
results are presented in Section 4 and Section 5 concludes the paper.

2. DEHAZING WITH MDCP

The MDCP method [5] is based on the Dark Channel Prior method [3] which generates a prior that is used to compute the dehazed image. The model used is a dichromatic model,

\[ \hat{x}(i, j) = t(i, j)x(i, j) + (1 - t(i, j))a, \]

(1)

where the hazy RGB image \( x \) at pixel location \( (i, j) \) is a composition of the attenuated non-hazy image \( x \) by transmission \( t(i, j) \) and the veiling \( (1 - t(i, j))a \) with \( a \) being the airlight vector [2, 3, 4]. The transmission has been described as an exponential decaying term,

\[ t(i, j, \lambda) = e^{-\beta(i,j)\lambda d(i,j)}. \]

(2)

with scattering coefficient \( \beta \), wavelength \( \lambda \), and distance from camera to radiant object \( d \). A common approach to simplifying (1) and (2) is to assume the scattering is homogenous and independent of wavelength [6]

\[ t(i, j) = e^{-\beta(i,j)\lambda}. \]

(3)

For some scenes, instead of assuming homogeneous scattering, we can assume relative flat depth but spatially varying scattering (e.g., smoke in fire scenarios)

\[ t(i, j) = e^{-\beta(i,j)d}. \]

(4)

where the transmission (3) and (4) only differ in interpretation.

After the airlight is estimated [2, 3], the transmission image is created using the MDCP image prior \( \theta_M \). The MDCP is generated by first grabbing a minimum color value for each pixel and then applying a median filter which is used for enforcing smooth transitions while preserving occlusion boundaries,

\[ \theta_M(i, j) = \min_{k, l \in \Omega(i, j)} \left( \frac{\hat{x}(k, l, c)}{a(c)} \right). \]

(5)

where \( \hat{x}(k, l, c) \) is the \( c \)th hazy color component at pixel location \( (k, l) \) and \( a(c) \) is the \( c \)th color component of the airlight vector \( a \). The transmission is then estimated using a linear combination of (5)

\[ t_M(m, n) = 1 - w\theta_M(m, n), \]

(6)

with \( w \) set to 0.95 for our experiments. Finally, the dehazed image is computed with

\[ \hat{x}_M(i, j) = \frac{\hat{x} - a}{\max(t_M(i, j), \epsilon)} + a, \]

(7)

with \( \epsilon \) chosen to be small (e.g., 0.1) for mathematical conditioning.

For images with very high resolution (e.g., 2000x2000), the computation time for \( \theta_M \) will still take a considerable amount of time because of the median filter operator. For these sizes, \( \theta_M \) can be computed with a scaled-down version of \( \hat{x} \) in (5) and then scaled up in (7) without much degradation because smooth depths are still enforced while edges are preserved.

3. LOCAL CONTRAST ENHANCEMENT

By enhancing the local contrast in the transform domain, we recover the details that may be degraded in the dehazing process.

3.1. Block gradient in DCT Domain

Let \( F \) be the DCT block for an \( N \times N \) image block \( f \). \( F(u, v) \) is the DCT coefficient at \( (u, v) \) and \( f(i,j) \) is the value of the image pixel at \( (i,j) \). The local image contrast can be measured using block gradient, defined as

\[ \hat{G} = G_{ver} \cdot \hat{j} + G_{hor} \cdot \hat{i}. \]

(8)

where

\[ G_{hor} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (f(i,j) - f(i, N-j)) \]

(9)

\[ G_{ver} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (f(i,j) - f(N-i,j)) \]

(10)

\( G_{hor} \) and \( G_{ver} \) are horizontal and vertical block gradients, respectively.

The block gradient can be calculated from the odd DCT coefficients at the first column and the first row. From the DCT formulation [9], the odd DCT coefficients at the first column become

\[ F(2l + 1, 0) = \frac{\sqrt{2}}{N} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (f(i,j) - f(N-i,j)) \cdot \cos \left( \frac{2i+1}{2N} \right) \]

(11)

for \( l = 0, \ldots, (N/2-1) \).

Exploiting (11), each block gradient can be obtained from summing the odd DCT coefficients [9] in the following way

\[ G_{hor} = F(0,1) + \frac{1}{4} F(0,3) - \frac{1}{4} F(5,0) - \frac{1}{4} F(7,0) \]

\[ G_{ver} = F(1,0) + \frac{1}{4} F(3,0) - \frac{1}{4} F(5,0) - \frac{1}{4} F(7,0). \]

(12)

3.2. Gradient oriented local contrast enhancement

The \( n \)th frequency bands at horizontal and vertical directions consist of DCT coefficients in each direction. Thus, the \( n \)th frequency bands for the horizontal and vertical directions are respectively

\[ \Omega_{hor}^n = [F(n,0), F(n,1), \ldots, F(n,N-1)] \]

\[ \Omega_{ver}^n = [F(0,n), F(1,n), \ldots, F(N-1,n)] \]

(13)

where \( n = 0, \ldots, (N-1) \). The HVS based contrasts at the \( n \)th band are measured at each direction by local energy variation ratio [7]. So,

\[ c_n^\alpha = (n+1) \cdot \frac{||\Omega_n^\alpha||}{\sum_{l=0}^{N-1} ||\Omega_l^\alpha||}, \quad \alpha = hor, ver. \]

(14)

where \( || \cdot || \) means the \( L^2 \) magnitude. Thus, the local contrast at \( (u, v) \) in the transform domain becomes

\[ c_{u,v}^\alpha = (c_{u,hor}^\alpha, c_{v,ver}^\alpha). \]

(15)

Denote \( \tilde{c}_n^\alpha \) as the directional enhanced contrast of the \( n \)th band, then the local enhanced contrast at \( (u, v) \) is expressed as

\[ \tilde{c}_{u,v} = (\lambda_{u,hor} \cdot c_{u,hor}, \lambda_{v,ver} \cdot c_{v,ver}) \]

(16)

where \( \lambda_n^\alpha \) is the enhancement factor for each direction \( \alpha \).
The directional contrast enhancement can be derived in terms of the energy variation ratio. Let \( \Omega_n^\alpha \) be the \( n \)-th directional enhanced frequency band. Using (14) and (16), the directional enhanced contrast is related to the enhanced frequency band defined as follows:

\[
\hat{c}^\alpha_n = (n + 1) \cdot \frac{||\Omega_n^\alpha||}{\sum_{l=0}^{\bar{\Omega}} ||\Omega_l^\alpha||}
\]

\[
= \lambda_n^\alpha \cdot (n + 1) \cdot \frac{||\Omega_n^\alpha||}{\sum_{l=0}^{\bar{\Omega}} ||\Omega_l^\alpha||},
\]

(17)

This equation enforces a relation between the enhanced band and the original band using the local energy variation ratio

\[
||\hat{\Omega}_n^\alpha|| = \lambda_n^\alpha \cdot R_n^\alpha \cdot ||\Omega_n^\alpha||,
\]

(18)

where the local energy variation ratio \( R_n^\alpha \) is

\[
R_n^\alpha = \frac{\sum_{l=0}^{\bar{\Omega}} ||\Omega_l^\alpha||}{\sum_{l=0}^{\bar{\Omega}} ||\Omega_l^\alpha||}, \quad \alpha = \text{hor, ver}.
\]

(19)

From (18), the enhanced frequency bands are recursively calculated from the lower frequency bands with updates using the local energy variation ratio.

Using (13) and (18), the enhanced DCT coefficients in each direction are derived with respect to the original DCT coefficients as follows:

\[
\hat{F}^\alpha(u,v) =
\begin{cases}
F(u,v), & \text{for } 0 \leq u \text{ or } v \leq \left\lfloor \frac{\bar{\Omega}}{2} \right\rfloor \\
\sqrt{\lambda_n^\alpha \cdot R_n^\alpha} \cdot F(u,v), & \text{for } \alpha = \text{hor} \\
\sqrt{\lambda_n^\alpha \cdot R_n^\alpha} \cdot F(u,v), & \text{for } \alpha = \text{ver}
\end{cases}
\]

(20)

Therefore, the DCT coefficients for locally enhanced contrast are obtained as

\[
\hat{F}(u,v) = F^\text{hor}(u,v) + F^\text{ver}(u,v).
\]

(21)

To avoid blocking artifacts, the local contrast should be enhanced along the direction perpendicular to the edge gradient direction that is same as the edge direction. By weighting each direction with the block gradient, we adjust the contrast enhancement according to the edge direction. The DCT coefficients which enhance the local contrast along the edge direction can be obtained by

\[
\hat{F}(u,v) = \frac{G^\text{ver}}{G^\text{hor} + G^\text{ver}} \cdot \hat{F}^\text{ver}(u,v) + \frac{G^\text{hor}}{G^\text{hor} + G^\text{ver}} \cdot \hat{F}^\text{hor}(u,v).
\]

(23)

For deciding the enhancement parameter \( \lambda \), we conducted subjective tests for various images. We set both horizontal and vertical enhancement parameters to be \( \lambda = 3 \).

Fig. 1 shows the results of local contrast enhancement compared to conventional methods. The method of [7] causes blocking artifacts because low frequency bands are modified. Although the method of [8] reduces blocking effect, it causes ringing artifacts along sharp edges. Due to the reduction of blocking and ringing artifacts, this proposed method produces the best score in the JPEG quality measurements (JPEG QM) [10] that is commonly used to measure image quality.

4. EXPERIMENT

The proposed method is applied to a fireman image that has low contrast due to heavy smoke. The size of the image is \( 2000 \times 1312 \), therefore, it was scaled down by a factor of 8 to estimate the transmission in (6), then scaled up before using (7) in order to reduce the amount of time for processing.

Fig. 2.(a) ~ (c) show the results at each phase. In Fig. 2.(b), the MDCP dehazing removes a great deal of overall smoke while preserving the color. However, since the smoke and depth are both spatially variant, thicker patches of smoke are still present in the image. As seen in Fig. 2.(c), the local contrast enhancement revives the details which are degraded during the dehazing process and achieves better color vividness. It also diminishes the smoke patches. This is because the proposed local contrast enhancement adaptively emphasizes the image details covered by smoke. Fig. 3 shows results for other image.

![Fig. 1. Comparison of local contrast enhancements](image-url)
5. CONCLUSION

We proposed a dual domain method (spatial and frequency) to improve the visibility of foggy or smoggy images by first dehazing fog or smog in the spatial domain and then enhance details (local contrast) in the transform domain. The proposed method removes fog or smog while improving the details in the images. The proposed method has low complexity since the dehazing method is computed on a decimated version and the image enhancement method is performed on the DCT coefficients.

6. REFERENCES


