Agricultural Image Defogging Based on Wavelet Analysis

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Abstract

In order to enhance the reliability and robustness of agricultural environment in foggy weather and to improve the agricultural image degradation collected in foggy days and the dim brightness and supersaturation of restoration result of traditional de-fogging algorithm, this paper based on the analysis of its degradation mechanism, adopts Curvelet wavelet transform method in the study of sharpening technology of degraded agricultural image under foggy weather from two perspectives: image restoration and image enhancement. The anisotropy of Curvelet wavelet transform is more suitable for analyzing the curve- and straight-line edge features and accords with the three features of the “optimal” image representation method pointed out by physiologic research: multi-resolution, band-pass and directionality. As the color of any image is formed by the mutual overlap of the colors of R, G, B channels and these three channels of the image are correlated, the method of this paper is to decompose the image in RGB space, perform Curvelet wavelet transform to R, G, B components and decompose it into many sub-band components of different scale frequencies. Then, it blends R, G, B components and reconstructs the restored image. The experiment proves that the algorithm of this paper has better de-fogging effect on degraded agricultural image and improves the dim brightness and supersaturation of restoration result of conventional de-fogging algorithm.

Key words: Agricultural Image Defogging, Wavelet Analysis, Curvelet Transform, Image Enhancement.

1. Introduction

With the deterioration of natural environment, hazy weather has already become a common weather phenomenon. It has low visibility, a long time of duration and a wide range of existence. Under this circumstance, the image photographed by agricultural imaging system will become fuzzy under the impact of fog [1]. Generally, foggy image has the following characteristics: low contrast, poor color fidelity, narrow histogram distribution and reduced scene visibility and so on. So, both the visual effect and post-processing of such kind of agricultural image will suffer different levels of influence and prevent the relevant analysts in acquiring the information of agricultural image from making correct judgment [2]. Wavelet transform is a non-stationary signal analysis method with strong local time and frequency analysis functions and it has been successfully applied in the field of feature extraction of signals [3]. As a new generation of multi-scale geometric analysis tool, wavelet transform has better recognition effect and it considers the information of scale, position and angle so that it has distinct advantages in the representation of the curves in the image. In order to overcome the insufficient definition, vignetting effect and distorted sky caused by traditional de-fogging algorithms, this paper uses Curvelet wavelet basis method to decompose, restore and reconstruct foggy degraded agricultural image and perform image sharpening and it significantly enhances the contrast and definition of restored image.

The emergence of wavelet analysis method can be traced back to Haar orthonormal basis proposed by Haar in 1910 and the L-P theory built upon Fourier series by Littlewood-Paley in 1938. In 1986, Meyer-a French mathematician, had successfully constructed the orthonormal basis with certain attenuation. In 1987, Mallat used the concept of multi-resolution analysis, unified the construction of various previous specific wavelets and came up with Mallat fast wavelet decomposition and reconstruction algorithm. In 1988, Daubechies constructed the compactly supported orthogonal wavelet. Donoho and others brought forward Curvelet transform theory and its anisotropy is very good for efficient representation of image edges [4]. This characteristic has helped Curvelet transform draw considerable attention from relevant researchers since it appeared in 1999 and it has also made plenty of research achievements in image processing and analysis. Image de-fogging algorithms are mainly based on non-model and model [5]. Non-model based de-fogging is to enhance the dynamic range of the brightness value of image with image enhancement methods, amplify image detail information and maximize the difference between the scenery of interest and its background in the image so as to make it more easily recognized by human eyes. On the other hand, model-based de-fogging explores the essential reasons behind image degradation from the imaging process, constructs the degradation model and conduct image de-fogging with it. However, the above two kinds of image de-fogging algorithms both have their limitations [6]. This
paper uses Curvelet transform to decompose the foggy degraded image into many sub-band components with different scale frequencies. High-frequency components are the edges and contour of the image while low-frequency part is mainly the information of object scenery, including rain and fog, etc. On one hand, it conducts threshold de-noising to high-frequency sub-band components, increases high-frequency coefficients and improves the contrast and detail definition. On the other hand, it performs unsharp masking to low-frequency sub-band components and reduces the approximate coefficients of low-frequency sub-band components. After high- and low-frequency components are processed respectively, de-fogging and sharpening effect can be obtained.

In the first place, this paper makes a preliminary introduction of the study of image restoration in foggy days from the research purpose and significance, the research status at home and abroad, the degradation principles and characteristics of foggy agricultural image as well as the objective evaluation methods of de-fogging effect. In the second place, it elaborates the principles of wavelet analysis and Curvelet transform and comes up with an agricultural image de-fogging method based on Curvelet wavelet analysis. In the last place, the simulation experiment proves that the algorithm of this paper is effective.

2 Agricultural Image Defogging

In broad sense, fog includes such physical phenomena that limit visual effect, including fog, haze, dust storm and smoke. Under the influence of fog, the light passing the object surface is absorbed and reflected by atmospheric particulates; in this way, the image obtained has bad quality, blurry details and dim colors[11]. The atmospheric scattering model describes the imaging mechanism affected by both haze and light. Sunlight becomes reflected light \( J(x) \) in the object surface. The reflected light scatters while passing through the fog and only part of the energy \( J(x) t(x) \) can reach the camera. Meanwhile, sunlight also scatters and becomes atmospheric light \( \alpha \) in the surface of suspended particles and the atmospheric light is received by the camera. Therefore, the imaging \( I(x) \) in the camera is made up of two parts: the transmitted object brightness \( J(x) t(x) \) and the scattered atmospheric light \( \alpha (1 - t(x)) \).

\[
I(x) = J(x) t(x) + A (1 - t(x)) I(x) = J(x) t(x) + A (1 - t(x))
\]  

(1)

Here, \( t(x) \) is the medium transmission, just as its name implies, it refers to the ratio which is successfully traversed and reached the camera. Therefore, transmission is inversely proportional to the distance \( d(x) \) between the object and the camera: the further away the object is from the camera, the more impact it suffers. When the distance \( d(x) \) approaches to infinity, the transmission \( t(x) \) is close to 0 and \( I(x) \) close to \( \alpha \), \( \alpha = \max y \in \{ x | t(x) \leq t_o \} I(y) \). To sum up, the core to de-fogging is how to estimate the medium transmission \( t(x) \) more accurately.

Usually, the basic model of image de-fogging can be represented with the following formula.

\[
I(p) = t(p) J(p) + (1 - t(p)) A
\]  

(2)

Here, \( J(p) = (Jr(p), Jg(p), Jb(p))T \) represents the original image (i.e. the image without fog) and \( I(p) = (Ir(p), Ig(p), Ib(p))T \) refers to the image we observe (namely the foggy image). \( r, g, b \) are the three components of the pixel at position \( p \). \( A = (Ar, Ag, Ab)T \) is the global atmospheric light and it represents the atmospheric light in the surrounding environment.

Besides, \( t(p) \in [0,1] \) is the transmission of the reflected light and it is determined by the distance between the scene point to the camera. The further the distance of light propagation, the scattered and weakened the light becomes. So, what the above formula means is that to mix the image \( J \) not enveloped by fog with atmospheric light \( A \) in a certain ratio and obtain the foggy image we finally observe [7].

To the image with many changes in depth, it is difficult for histogram equalization algorithm to reflect the changes in depth of the local scene in the image and the scene image is not natural due to the interference of many noises. The foggy image obtained dark channel de-fogging algorithm is rather dim and it cannot process large-area sky or similar areas. Besides, for the foggy image of large-area sky or of large-area snow scene, it is bad in de-fogging effect and there is too much color cast.
3. Fourier Transform and Curvelet Wavelet Transform

3.1. Fourier Transform

The concept of short-time Fourier transform (STFT) is as follows: if \( W \in L^2(R) \) is selected to make \( W \) and its Fourier transform \( \hat{W} \) meet the following:

\[
W(t) \in L^2(R), \hat{W}(\omega) \in L^2(R)
\]  

(3)

then, use \( W \) as the window function and the window Fourier transform introduced in Formula (4) is called as Short-Time Fourier transform (STFT):

\[
(\hat{g}_b(f))(\omega) = \int_{-\infty}^{\infty} (e^{-j\omega t} f(t)) \hat{W}(t-b)dt
\]  

(4)

When Gaussian function is selected as window function, it is Gabor transform.

The defect of STFT is that the size and shape of the analysis window is fixed. As the frequency is inversely proportional to the cycle, the high-frequency components which reflect the signal need narrow time window while the low-frequency components of signal require wide time window. STFT cannot meet the requirements. Besides, STFT has much redundancy and it increases unnecessary computation [8] [9].

3.2. Curvelet Transform

Curvelet transform as a multi-scale analysis method, inherits the excellent local properties of wavelet transform in spatial domain and frequency domain. It is more suitable to analyze the curve or straight-line edge features in 2D image and it has higher approximation accuracy and better sparse representation ability [10].

Curvelet introduces a rotation change on the basis of stretch and translation. The construction of 2D Curvelet basis is rather complex.

\[
\varphi_{a,b,\theta}(\chi) = a^{-3/4} \varphi(D_a R_\theta \chi-b))
\]  

(5)

Here, \( \chi \) is the 2D vector, \( D_a \) is the 2D stretch function, \( R_\theta \) is the 2D function of rotation angle of \( \theta \), \( b \) is the translation coefficient and \( \varphi_{a,b,\theta}(\chi) \) is obtained from \( \varphi \) transform after performing a stretch, \( b \) translation and \( \theta \) angle rotation (please note the order) to the 2D vector \( \chi \):

\[
D_a = \begin{bmatrix} 1/a & 0 \\ 0 & 1/a, \sqrt{2} \end{bmatrix}
\]  

(6)

\[
R_\theta = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix}, R_\theta^{-1} = R_\theta^T = R_{-\theta}
\]  

(7)

\[
a_j = 2^{j/2} \theta_{j-j} = 2\pi l \cdot 2^{3/2} \text{low}(j/2)
\]  

(8)

\[
b_k^{(j,l)} = R_{\theta_j}^{-1} (k_2 2^{-j/2}, k_1 2^{-j/2})
\]  

(9)

\[
\varphi_{j,l,k} = \varphi_{a,b,\theta}^{(j,l)}(\chi)
\]  

(10)

\( \varphi_{j,l,k} \) function with an integer subscript is obtained by discretizing \( a, b \) and \( \theta \) in \( \varphi_{a,b,\theta}(\chi) \) with integer. (the \( j, k, l \) here are the changes in the integer domain and low is the integer function smaller than this number)

Apply Curvelet transform into image fusion technology and restore the feature information of the original image more accurately. With the increase of scale, namely the scale changes from the optimal scale to the largest scale, the “needle” graphic components in the spatial domain become smaller while the “needle” graph in the frequency domain becomes bigger. It can be learnt from the certain symmetry between spatial domain and frequency domain that the “fatter” the spatial domain, the “thinner” the frequency domain. The bigger value, the
more possible it represents high-frequency information [12] [13]. The following Fig.1 is the space-time transformation of curvelet.

![Figure 1. The space-time transformation of curvelet](image)

4. Method of This Paper

Atmospheric light is usually estimated by the brightest color in the image. As plenty of dust-haze usually results in a shiny or whitish color, the object with colors brighter than atmospheric light is selected; in this way, a result which shall not be taken as the reference value of atmospheric light will be used as the estimation of atmospheric light. We select the color (including \(R, G, B\) components) with the shortest distance \(\| (Ir(p), Ig(p), Ib(p)) - (255,255,255) \|\) as the reference value of atmospheric light. Please be noted that the significance of such action is that we hope to select the color closest to pure white, namely the brightest color, as the reference value of atmospheric light.

1. Read in the image.
2. Take \(R, G, B\) components of input image, conduct data conversion to \(R, G, B\) components and take the logarithm.
3. Perform Curvelet transform to \(R, G, B\) components, obtain some sub-band coefficients of different high- and low-frequencies and constitute Gaussian filter function.
4. Perform convolution operation to \(R, G, B\) components and Gaussian filter function. In the log domain, subtract the image after low-pass filter with the original image and obtain enhanced high-frequency image. Convolution operation in essence, is the filter process of an image and the convolution kernel is equivalent to a filter. The mathematical formula of convolution operation is as follows:

\[
g(i, j) = f(i, j) \otimes w = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) * f(i-s, j-t) \tag{11}
\]

In Formula (11), \(g(i, j)\) and \(f(i, j)\) represent the value of the pixel point with \((x, y)\) as the coordinate in the output image and input image respectively and \(w\) is convolution kernel.
5. Perform unsharp masking to low-frequency sub-band coefficient and threshold de-noising to high-frequency sub-band coefficient, take cologarithm; obtain enhanced image components and conduct contrast stretch enhancement to the enhanced image. Perform Retinex brightness enhancement and weighting to every \(R, G, B\) component. Then conduct automatic stretch to \(R(x, y)\) and automatic stretch can avoid the loss of image information, as shown below.
\[ R_{\text{out}}(x, y) = 255 \times \frac{R(x, y) - \min(R, G, B)}{\max(R, G, B) - \min(R, G, B)} \] (12)

\(R(x, y)\) is the intensity value of reflected light of atmospheric light by the scenery.

(6) Perform inverse Curvelet transform reconstruction to different processed high- and low-frequency sub-band coefficients and obtained de-fogged image components.

(7) Fuse the enhanced \(R, G, B\) components and display the operation result.

5. Testing Experiment and Analysis

In this part, simulation experiment is conducted to verify the effectiveness and applicability of the algorithm in this paper. The experiment is achieved with Intel(R) Core(TM) i7-4610M as the processor and Windows 7 as the operating system with Matlab programming. It compares the algorithm of this paper, histogram equalization de-fogging algorithm and dark channel de-fogging algorithm from every perspective.

![Figure 2. Comparison of de-fogging effect](image-url)
Figure 3. Comparison of de-fogging effect

It can be seen from the comparison of local effect after de-fogging that after the image is processed by the algorithm of this paper, green plants are still bright in colors and although the distant background is slightly dim in colors, it still maintains the original colors and the ground color is also normal. After being processed by dark channel de-fogging algorithm, both the color of the soil and the lawn are dark and the background in the distance also has color cast with the color in the upper part is reddish. After histogram equalization de-fogging algorithm, the color of the soil is dark yellow, but the lawn color is well preserved. The background edges far away have obvious color fringes, the upper region has serious color cast and the surrounding region has noise points. Therefore, whether in the drawing of overall effect or the drawing of partial enlargement, the algorithm of this paper leads to better visual effect.

6. Conclusions

In recent decades, foggy image restoration technique has already become one of the hot topics in the research of computer image processing. This paper has come up with an agricultural image de-fogging algorithm based on Curvelet wavelet transform for the restoration of foggy agricultural image. This algorithm uses Curvelet transform to decompose foggy degraded image into numerous sub-band components of different scale frequencies. High-frequency components are the edges and contour of the image while low-frequency part is mainly the information of object scenery, including rain and haze, etc. On one hand, it conducts threshold denoising on high-frequency sub-band components, increases high-frequency coefficients and improves the contrast and detail definition. On the other hand, it performs unsharp masking to low-frequency sub-band components and reduces the approximate coefficients of low-frequency sub-band components. After high- and low-frequency components are processed respectively, de-fogging and sharpening effect can be obtained. The final experiment has proven that the efficient representation of the image edges and details in the algorithm of this paper can make the processed image noises smoother and preserve the edges, textures and details of de-hazed image; in this way, its contour is clearer and visual effect is better.
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