

THE ELIMINATE INCONSISTENT ALGORITHM AND ENHANCEMENT OF LARGE PLANE ARRAY CCD IMAGES

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ABSTRACT:

Aiming at uneven illumination and low contrast of large plane array CCD images, this paper presents an effective algorithm to extract uneven illumination from images and enhance the contrast by using wavelet transform. Based on an analysis of the illumination model on a focal plane, emulational images are constructed for the illumination model. Through analysis of the wavelet transform coefficients of emulational images, it is found that information of illumination non-uniformity mainly appears in wavelet approximate coefficients, and detail information is contained in detail coefficients. Taking advantage of this property, the original image is first decomposed with multiresolution wavelet, next, the natural logarithms of approximate coefficients are calculated, and an appropriate attenuating operator is applied to implement the non-uniformity correction of approximate coefficients before exponentiating correction, linear contrast-stretch is applied to all the approximate coefficients, a nonlinear function is applied to each level detail coefficients to accomplish adaptive contrast enhancement, finally, uniform illuminative and contrast enhanced aerial images are acquired through reconstruction of images. The experiments show that the wavelet analysis method can achieve a satisfying effect of removing the uneven illumination for digital aerial images and keeping well detail image features, contrast enhancing aim is also achieved.

1. INTRODUCTION

The first large plane colour CCD digital aerial photogrammetry camera which made in China uses one 9k*9k pixels CCD to record the panchromatic image and three 2k*2k pixels CCD to record the RGB bands. Every CCD corresponding one independent optical system, the field of view of each lens is 60 degree. The image illumination of central projection optical lens is inconsistent, central area is brighter than around area, and image contrast is also a bit low. Through theory analysis, we find that the illumination attenuating model varies according to 4 time power cosine function. Several other factors are also affecting the image illumination, except for lens structure and camera machining techniques. For example, the elimination of multi-channel inconsistent of large plane CCD image also affects the image illumination attenuation model^[1]. How to eliminate the inconsistent of image illumination and improve the image contrast is very necessary.

MASK dodging algorithm was introduced in [2] and [13] to eliminate the illumination inconsistent of aerial images. It's considered that the original image is the superposition of an even illuminating image and an uneven illuminating background image, the correction of uneven illumination is to subtract the background image from the original image. In this scheme, the background image must be simulated accurately beforehand, but the background image is affected by many factors, it's difficult to construct it. Furthermore, the background images of different images are also different. The background image can be considered to be low frequency signals comparing to the image signal. Wavelet analysis method

which has multiresolution analysis character is considered in this paper. An advantage of wavelet transform is that the time-frequency windows vary. In order to isolate signal discontinuities, one would like to have some very narrow basis functions. At the same time, in order to obtain detailed frequency analysis, one would like to have some very long basis functions. A way to achieve this is to have short high-frequency basis functions and long low-frequency ones. This happy medium is exactly what you get with wavelet transform^[3].

After analysis and validation, it is found that the main illumination information of the whole image is contained in the approximate coefficients, and the detail coefficients contain the detail information. Through adjusting the approximate coefficients, the illumination un-uniformity of the image can be corrected, at the same time the detail information can also be enhanced by adjusting the detail coefficients.

2. OPTICAL LENS VISUAL FIELD ILLUMINATION ATTENUATING MODEL ANALYSIS

As shown in Figure 1, S_0 represents out pupil plane, $\vec{n}_0$ radius vector of principle point, and $\vec{n}$ radius vector of non-principle point, ω the angle between $\vec{n}_0$ and $\vec{n}$. Because the image plane is lightened by S_0 , so the radiant intensity relation between the principle point (I_0) and non-principle point (I) is as below^[4]:

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$$I = I_0 \cos \omega \quad (1)$$

When $\omega = 0$, it's the principal point illumination:

Notice that the relation between L_0 and L is as follow:

$$L = \frac{L_0}{\cos \omega} \quad (2)$$

Because the diameter of the out pupil is much smaller than the distance between the pupil and the image plane, so for analyzing convenience, we calculate the illumination of the image plane surface primitive with point light formula. Set dA the image plane surface primitive, and the solid angle between dA and S_0 is as below:

$$d\theta = \frac{\cos \omega dA}{L^2} \quad (3)$$

The radiant flux received by dA is as below:

$$d\phi = Id\theta = \frac{I \cos \omega}{L^2} dA \quad (4)$$

The radiant intensity is as below:

$$E = \frac{d\phi}{dA} = \frac{I}{L^2} \cos \omega \quad (5)$$

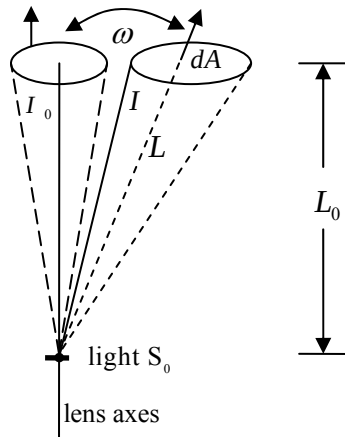


Figure 1. Diagram of principal point and non-principal point illumination. Put formula (1) and (2) in (5), we got the non-principal point illumination formula :

$$E = \frac{I_0}{L_0^2} \cos^4 \omega \quad (6)$$

$$E_0 = \frac{I_0 * dA}{L_0^2} \quad (7)$$

Then we find the relation between the principal point illumination and the non-principal point illumination:

$$E = E_0 \cos^4 \omega \quad (8)$$

Equation (8) gives the illumination relation between the principal point and the non-principal point in the ideal diffraction optical system.

The illumination is affected by several factors, and the image plane illumination model of real optical system is a complicated model, so it can't be represented by a equation; we can get several logical conclusion of the illumination of the image plane as follows:

- (1) The whole illumination model is the liner superposition of the model based on (8) with other attenuating models;
- (2) Other attenuating models are also continuous functions;

The addition of continuous functions is also continuous function, so it's rational to conclude that the whole illumination model is an unknown continuous function. This conclusion indicates that some wavelet coefficients are sensitive with it and some are not. In the following section the wavelet coefficients will be first discussed, and using the equation (8) to form a simulated image to validate the theory analyses.

3. LUMINANCE SENSITIVE WAVELET COEFFICIENTS ANALYSES

One level wavelet decomposition of discrete signal samples

$$c_k^1 = \sum_n h_{n-2k} c_n^0 \quad (9)$$

$$d_k^1 = \sum_n g_{n-2k} c_n^0 \quad (10)$$

Where h_{n-2k} is a low pass filter, g_{n-2k} is a high pass filter, c_n^0 is the original signal, c_k^1 is the approximate coefficients, d_k^1 is the detail coefficients.

The reconstruction formulation is:

$$c_n^0 = \sum_k h_{n-2k} c_k^1 + \sum_k g_{n-2k} d_k^1 \quad (11)$$

The wavelet transform of image is thrown in Figure 2. Boundary problem in wavelet transform is deal according to [3]. One $N \times N$ size image after one level wavelet transform becomes four $(N/2) \times (N/2)$ size sub band images^[6-9]. These images represent the approximate coefficients (LL), the

horizontal detail coefficients (LH), the vertical detail coefficients (HL), and the diagonal detail coefficients (HH)^[10].

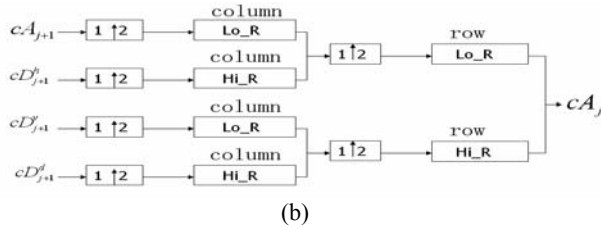
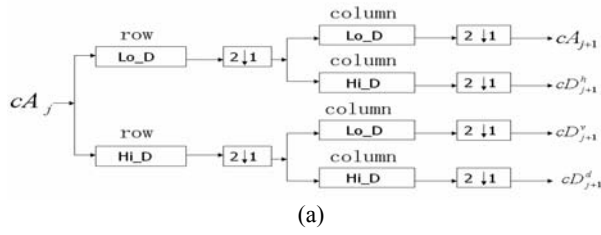


Figure 2. Diagram of 2-D WT decomposition (a) and reconstruction (b)

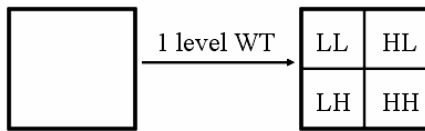


Figure 3. Diagram of Single-level 2-D wavelet transform

The attenuating illumination model represented in formula (8) shows that the illumination attenuates slowly from the image central point to the around. This means that, the illumination attenuating model corresponding to the low frequency part. In wavelet transform, the low frequency signal is correspond to the approximate coefficients. So it can be concluded that the approximate coefficients are most sensitivity to the illumination attenuation. While the detail coefficients correspond to the detail information such as image edges.

For testing the above feature, emulational image of even illumination image is given in Figure 4, illumination non uniform model accord to $\cos^4 \omega$ is given in Figure 5. After one level wavelet transform of these two figures, wavelet coefficients are shown from Figure 6 to Figure 9.

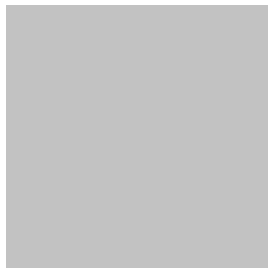


Figure 4. Emulational image of uniform illumination model

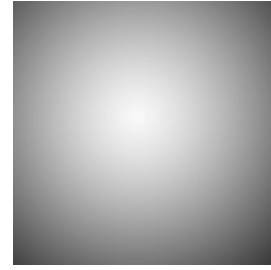


Figure 5. Emulational image of non uniform illumination model

We can see that approximate and detail coefficients of the even illumination image are almost in a plane, and the uneven illumination image detail coefficients are almost in a plane, only the extent enlarged, but the approximate coefficients is not in a plane at all.

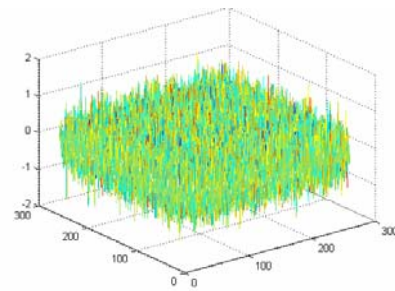


Figure 6. Grid figure of detail coefficients of 1-level wavelet transform of non uniform illumination image

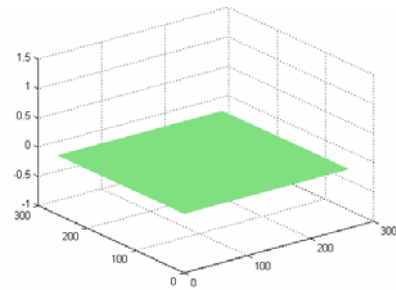


Figure 7. Grid figure of detail coefficients of 1-level wavelet transform of uniform illumination image

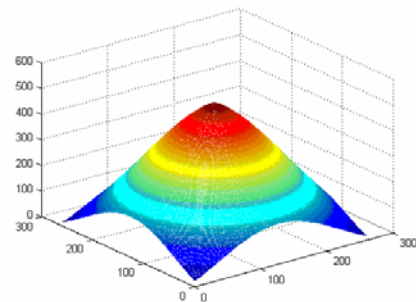


Figure 8. Grid figure of approximate coefficients of 1-level wavelet transform of non uniform illumination image

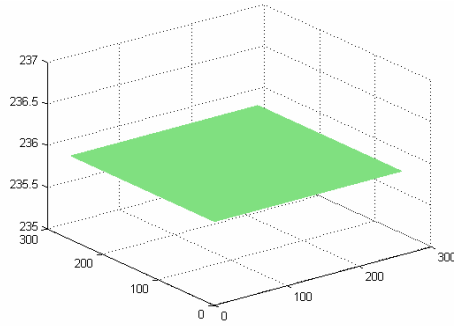


Figure 9. Grid figure of approximate coefficients of 1-level wavelet transform of uniform illumination image

Three conclusions can be deduced after analysis of these figures
 (1) Illumination attenuating model corresponding to the low frequency signal;
 (2) Approximate coefficients are most sensitive to the varying of illumination;
 (3) Detail coefficients corresponding to the detail information of the image;

Based on these conclusions, we can believe that the illumination equalization can be achieved by adjusting the approximate coefficients, and the detail information of the image can be enhanced by adjusting the detail coefficients.

4. WAVELET COEFFICIENTS ADJUSTING SCENARIO

4.1 Approximate Coefficient Adjusting Method

One attenuation operator is applied to the approximate coefficients which are to mitigate the big coefficients and augment the small ones. This operation can make the approximate coefficients much smooth.

Experiment results show that if only adjust the highest level approximate coefficients, the image visual effect will be very abruptly. Adjusting the approximate coefficients level by level and reconstructing the image can get better result.

The original image is first decomposed with four level wavelet transform, we choose db4 wavelet in experiment. Next, the natural logarithms of approximate coefficients of each level are calculated, noted as $A(x, y)$ and then an appropriate attenuating operator $\Phi(x, y)$ [11] is applied to implement the non-uniformity correction of approximate coefficients.

$$\Phi(x, y) = \frac{\alpha}{A(x, y)} * \left(\frac{A(x, y)}{\alpha} \right)^\beta \quad (12)$$

where α is the average value of the approximate coefficients of that level, β is a parameter which is used to adjust the contrast of the image, it's value is usually between 0.9 to 1.0.

Detail information contained in different level is different, high level approximate coefficients contain less detail information, the attenuation degree is much less, and β is a bit smaller, moreover, the small scale approximate coefficients contain

more, and β is a little big. through this process the whole illumination is balanced.

By attenuating the big coefficients and enhancing the small coefficients, we adjust the approximate coefficients in different scales, and then a linear stretch is applied to all the approximate coefficients, so as to adjust the whole illumination. From these steps the illumination of image is more balanced.

4.2 Detail Coefficient Adjusting Method

Detail information is contained in the detail coefficients; by enhancing these coefficients the detail information of the image can be enhanced. We suppress coefficients of very small amplitude and enhance only those coefficients that are large within each level of transform coefficients. Equation (13) is used to accomplish this nonlinear operation [12].

$$f(y) = a[\text{sigm}(c(y-b)) - \text{sigm}(-c(y+b))] \quad (13)$$

Where

$$a = \frac{1}{\text{sigm}[c(1-b)] - \text{sigm}[-c(1+b)]} \quad 0 < b < 1$$

sigm(x) is defined by

$$\text{sigm}(x) = \frac{1}{1 + e^{-x}}$$

b and c control the threshold and rate of enhancement, respectively. It can be easily shown that $f(y)$ is continuous and monotonically increasing in interval $[-1, 1]$. Furthermore, any order derivative of $f(y)$ exists and is continuous. Therefore, enhancement using $f(y)$ will not introduce any new discontinuities. In addition, $f(y)$ satisfies the conditions $f(0) = 0$ and $f(1) = 1$.

For the input detail coefficient y with maximum absolute amplitude $y_{\max}$, we map the coefficients range $[-y_{\max}, y_{\max}]$ onto the interval $[-1, 1]$. This is accomplished by using $y_{\max}$ as a normalizing factor in (14). Thus, $f(y)$ may be written as $f(y) = a y_{\max} [\text{sigm}(c(y/y_{\max} - b)) - \text{sigm}(-c(y/y_{\max} + b))]$ (14)

The benefit of the normalization is that a, b, and c can be set independently of the dynamic range of the input coefficients. And last linear stretch is also applied to all the detail coefficients.

5. EXPERIMENTS RESULTS AND ANALYSIS

In experiment, large plane array CCD image of Guangzhou City is used. This camera can obtain four images in every expose instant which are the panchromatic image and the R G B band images. We also enhance the contrast of the image by contrast-limited adaptive histogram equalization. The result of the panchromatic image is given in Figure 10, 11 and 12.



Figure 10. Original aerial image



Figure 11. Adaptive histogram equalization result



Figure 12. Proposed method result

We assess the results in two aspects: qualitative and quantitative. In qualitative aspect, we assess them by visual interpretation. And in quantitative aspect, we measure the changes in the brightness and detail textures from the average intensity and average grads.

(1) Qualitative aspect

From the visual result, the brightness around the original image is distinctly dark and the central is bright in Figure 10. After disposing, as shown in Figure 12, the uneven phenomenon and the brightness in every part of the image get accordance. Meanwhile, the brightness of the whole image is well distributed. In figure 11, the brightness is not so even, especially in the corner.

(2) Quantitative aspect

The average value of the illumination and the grads of the image are shown in table 1. The average grads of the image calculation formula is as below^[13]:

$$\nabla \bar{G} = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N \left[\Delta_x f(i,j)^2 + \Delta_y f(i,j)^2 \right]^{\frac{1}{2}} \quad (15)$$

where $\Delta_x f(i,j)$, $\Delta_y f(i,j)$ are the one order difference values in the direction of x and y. The five local parts are corresponding to the top left corner, top right corner, central section, bottom left corner and bottom right corner of the image. The size of these parts is 170*170 pixels.

From the data in the table, we can get that brightness around the original image is distinctly dark and the central is bright. After using our method, the brightness in every part of the image gets accordance. Meanwhile, the average grads in the image is improved compared with original image, it means that the image contrast has been enhanced in some degree.

6. CONCLUSION

It realizes the image dodging and enhancing the detail features of the image through the wavelet transform to separate the low

frequency information and the high frequency information and disposing the low and high frequency coefficients separately. Experimental results show that the proposed method is effective for adjusting the contrast of large plane array CCD images.

In the application of engineering, it fulfils the uneven illumination and contrast enhancement of large plane array CCD images in four channels.

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	Original image		Adapt histogram equalization		Our method result	
	intensity mean	grads mean	intensity mean	grads mean	intensity mean	grads mean
local part						
up left	68.5	8.5	104.9	22.7	122.4	40.5
up right	64.4	7.2	93.8	20.9	121.5	36.4
central	142.4	15.9	129.3	31.6	141.9	56.8
bottom left	54.7	7.0	92.4	18.5	109.2	34.5
bottom right	62.1	7.7	97.7	20.0	118.6	38.4
whole	86.0	9.9	108.0	24.8	126.4	44.3

Table 1. Statistic parameters comparison