IMAGE QUALITY RELATED PROCESSING AND APPLICATIONS BASED ON RETINEX WAVELET THEORY

Qingwu HU, *
School of Remote Sensing and Information Engineering, Wuhan University, Wuhan, P.R. China, 430079

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ABSTRACT:
In this paper, a new image processing model based on Retinex technique and multi-resolution wavelet analysis together to simulate the imaging course and focus mechanism of HSV is proposed. At first, the image presentation based on the Retinex model of the lightness and colour perception of human vision, which is related to the neuropsychological functions of individual neurons in the primate retina, lateral geniculation nucleus, and cerebral cortex, is designed to decompose image into constant part and variance part with ill-problem. Secondly, the multi-resolution wavelet transformation is proposed as a multiple resolution observation and analyses of image to express the image with a changeable course in wavelet domain which is sensitive to the eye's psychology character of the human vision view effect and its adjustable focus performance. The corresponding imaging dodging enhancement and restoration algorithms in the Retinex wavelet (RW) domain are designed to improve image quality with different image defects. The image processing principle based on the Retinex wavelet analysis theory is exposed together with image processing applications of image mosaic of photogrammetry workstation. The large area mosaic experiment with different luminance and uneven tone image shows it can remove mosaic scar and obtain a seamless mosaic orthodox-image with smooth tone and colour transitions after the Retinex wavelet restoration processing.

1. INTRODUCTION

The unavoidable image quality problems become more and more outstanding affection to all kinds of image applications, which greatly affect the development and application of image understanding and image vision, such as automatic mapping, object automatic identification and artificial intelligence. Image qualities related processing is based on the common imaging model as equation 1(F.M.J. Starck, 1998, Rank, 1999).

$$g(x,y)=\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f(m,n)h(x-m,y-n)+n(x,y) \qquad (1)$$

Where $g(x,y)$ is quality-descending image, $f(x,y)$ is the real scene image, $n(x,y)$ is the random noise and $h(x,y)$ is imaging model. As we know, some part area in a degrade image or some objects in a degrade image can obtain good imaging and view effect even the surround area or other objects is imaged worse quality. In the other side, a degrade image with bad geometric shape characteristic maybe has well radiant feature. The image processing should be selective while the image processing based on the above traditional model is done the total image without differing image part with different operator. In fact, imaging course or imaging system is simulated to human vision system (HSV) and many researches on image processing technique combine the principle and characteristic of HSV (A. Blake, 1987). E. H. Land, 1971, 1977 proposed Retinex technique for imaging analysis and high quality image presentation, which have obtained marketable applications for improving classification accuracy of remote images, medical image enhancement to detect cancer (Z. Rahman, 2001). While Retinex technique is only to way of image presentation methods using constant decomposition, the image analysis should be done in the multi-resolution level, which is simulated to HSV. Wavelet analysis provides a multi-resolution image analysis tool for its best changeable focus performance, which is simulated to focus function of human optic nerve. Many classical methods have been proposed to solve such problems, including several multi-scale and wavelet based approaches (N. Bose, 1998, M. Elad, 1999, B. Tom, 2000). Retinex theory proposals an image representation accordant to imaging course while it has not the function of multiple resolution image analysis (D.J. Jobson, 1997, Z. Rahman, 1997, 1998, B. Thompson, 2000). Image analysis based on wavelet should be done with a suitable image representation to obtain best image quality.

In this paper, a new image processing model based on Retinex technique and multi-resolution wavelet analysis together to simulate the imaging course and focus mechanism of HSV is proposed. At first, the image presentation based on the Retinex model of the lightness and colour perception of human vision, which is related to the neuropsychological functions of individual neurons in the primate retina, lateral geniculation nucleus, and cerebral cortex, is designed to decompose image into constant part and variance part with ill-problem. Secondly, the multi-resolution wavelet transformation is proposed as a multiple resolution observation and analyses of image to express the image with a changeable course in wavelet domain which is sensitive to the eye's psychology character of the human vision view effect and its adjustable focus performance. The corresponding imaging dodging enhancement and restoration algorithms in the Retinex wavelet (RW) domain are designed to improve image quality with different image defects. The image processing principle based on the Retinex wavelet analysis theory is exposed together with image processing applications of image mosaic of photogrammetry workstation. The large area mosaic experiment with different luminance and uneven tone image shows it can remove mosaic scar and obtain a seamless mosaic orthodox-image with smooth tone and colour transitions after the Retinex wavelet restoration processing.

2. METHODOLOGY

Current image quality related processing algorithms and application cannot radically solve the uniform of image quality improvement, image quality assessment and different imaging sensors. The overall technique proposed in this paper is to obtain best imaging representation model simulated to imaging course and imaging analysis method of HSV, which it is called

* Corresponding author: Tel.:0086-27-87664633; Fax: :0086-27-87664633; Email: qwhu@263.net

as Retinex Wavelet theory (E. H. Land, 1971, 1977, D. J. Jonson, 1997 and D. H. Brainard, 1986). The representation mathematic model is constructed in the Retinex Wavelet domain and relevant fast algorithm is design for the image quality related processing including image dodging and image restoration. All these will be discussed in Section 2.1 to Section 2.3.

2.1 Image Representation and Analysis Based on Retinex Wavelet Theory

The basic assumption of retinex wavelet image representation is that the quality degrade image is consist of two parts. One is the constant part, which is the real imaging of object scene and the other is variance part with noise and distortion. Thus image quality processing should be done only to the variance part image. This assumption can be understood with different imaging model for different image quality related processing aim such as image enhancement and image restoration.
For image restoration, the assumption comes from imaging theorem of photograph. All of imaging physics course to an optic device is the same, which can meet imaging theorem as figure 3 shown (S.X. Zhang, 1994):

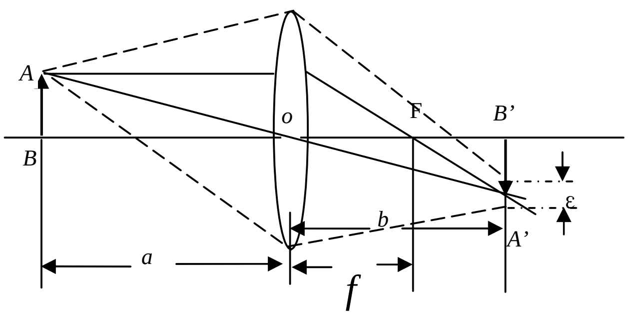

Figure 3 Imaging Theorem

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f} \qquad (2)$$

Where a is the distance of scene, b is the distance of image and f is focal distance. $A'B'$ is the image of scene object AB, ε is the diameter of imaging blur circle. As the above imaging course and imaging theorem, objects in different scene distance should adopt different focal distance strictly to obtain clear imagery as automatic focusing function of HSV to ensure the interested object being placed with best focal distance. To an imaging system, the focal length of optic sensor is stable during imaging course, thus it tries to use a suitable super focal length to obtain a large range of the depth of field with relative clear imagery. The super focal length with large depth of field is based on the estimation of imaging blur circle with a factor that a circle with a certain small diameter can be taken as a point to the sensitive resolution of HSV, which means the blur imagery inside the blur imaging circle can be taken as clear imagery. And the objects in the range of depth of field can obtain clear imagery with the estimation of blur circle. Even though, the final imagery of a large scene range especially the mountain terrain just has a stable imagery part with strict clear imaging and the other part should be re-focus to obtain clear imagery. Thus, image restoration should be done just to the imagery part not on the focal length while all of image restoration algorithms are based on the total imagery. In principle, the image restoration based on total imagery will damage the object imagery on the focal distance, thus these quality related processing should be done with two parts imagery representation. And once the imaging sensor and imaging state is confirmed, the clear imagery part is stable, which we called it constant imagery part.
For image enhancement, the assumption comes from illumination model as the figure 4 shown (B. K. P. Horn, 1974). As figure 4 shown, R is the light source, and A, B is the object in scene. The lightness of object A composes with the illumination I_{LR} from light source and reflectance I_{RB} from other object B, which can be illustrated as equation (3).

$$I = I_{RB} + I_{LS} \qquad (3)$$

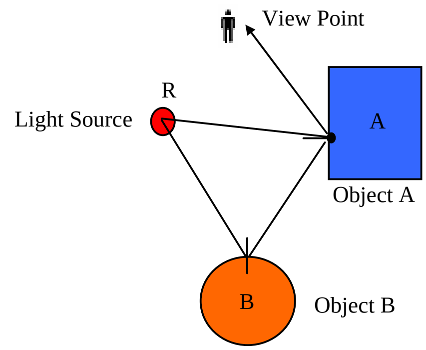

Figure 4 Illumination Model

Thus the final imagery can be decomposed into two different images of illumination image part and reflectance image part. Once the light source and its relationship between light source and object is confirmed, the illumination image part can also be taken as constant imagery part. Thus, the image brightness and colour processing should deal with these two images using different operator, which is not considerate by common image enhancement algorithms.
Whether imaging theorem or illumination model, they construct image with right imaging part and ill imaging part. This can be expressed a deconvolution model as equation (4):

$$G(\mathrm{x, y}) = \mathrm{R(x, y)\,L(x, y)} \qquad (4)$$

Where $G(x,y)$ is the degrade image through imaging model, $L(x,y)$ is the constant imagery part and $R(x,y)$ is the variance imagery part. For this image representation model, the image processing algorithms should adopt different operator to constant image and variance ill image. And the benefits of such decomposition include the possibility of improving image quality only to the ill-posed image part without damaging constant image part. Converse image representation model to the logarithmic domain by $g(x,y)$ = log $G(x,y)$, $l(x,y)$ =log $L(x,y)$, $r(x,y)$ = log$R(x,y)$, and thereby we can get:

$$g(x, \mathrm{y}) = l(x, \mathrm{y}) + r(x, \mathrm{y}) \qquad (5)$$

This step is motivated both mathematically, preferring additions to multiplications, and physiologically, referring to the sensitivity of our visual system]. Thus, the multiple-resolution analysis can be done only to the $r(x,y)$ to obtain higher precision image representation as equation (6) shown:

$$g(x, \mathrm{y}) = l(x, \mathrm{y}) + \sum_{kin} d_{k,n}\psi_{k,n}(x, \mathrm{y}) \qquad d_{k,n} = < f, \psi_{k,n} > \quad (6)$$

Where, $\psi_{k,n}$ is the two dimensions base function of wavelet transform. This is the image representation model based on Retinex Wavelet theory. Comparing with traditional imaging model (as equation (1) shown), this model is more closed to imaging course and focus mechanism of HSV. Image processing algorithms based on this representation model will be superior to common imaging model. Thus, the image processing procedure based on Retinex-Wavelet (RW) image representation model can be illustrated as figure 5:

As figure 5 shown, one of the key technique of RW model is to estimate the constant part image *l(x,y)*. D. J. Jobson, 2002, propose a statistic model based on grey distribution through the research of the statistics of visual representation to estimate *l(x,y)*. And iteration algorithms using a constant as an initial value to *l(x,y)* with probability model constraint to the r(x,y) are proposed in many color enhancement research. To different image quality processing, the estimation of *l(x,y)* will be difference. This will be discussed in the following Section 3.2, Section 3.3 and Section3.3.

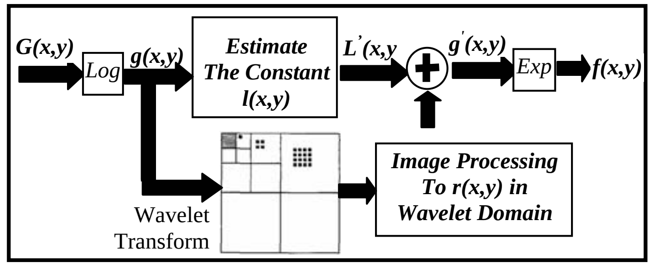

Figure 5 RW Imaging Model

2.2 Image Dodging in Retinex Wavelet Domain

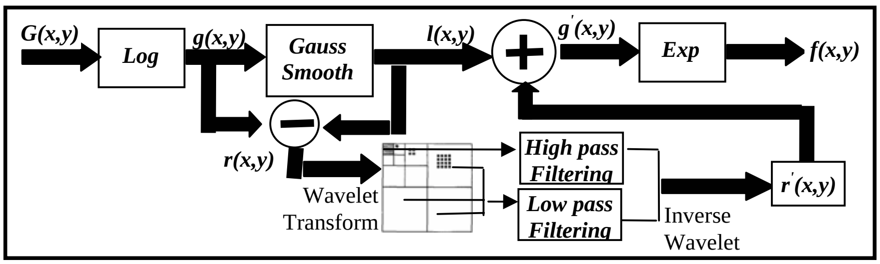

Figure 6 Dodging Processing Based on RW Model

In the aero-photograph, the distribution of intensity in the focus plane is not well-proportioned and gradually minish from centre to side when light get through the field lens of the huge camera. At the same time, building shadow and the factory fog affect the local contrast in the image. Anymore, the discord of illumination of the coteua in the side of exposed to the sun and back to the sun makes different contrast and grey distribution in the image (As figure 8 shown). All these in the image are showed as light decreasing around, asymmetry of intensity and hue, declination of contrast. To improve quality of these images is called image dodging and it can be classified into image enhancement.

For image dodging, the constant image *l(x,y)* can be taken as a blur Mask in traditional photograph copy. Thus we can taken the following assumptions to calculate reflectance image *r(x,y)*:

(1) The illumination is its spatial smoothness.

(2) The reflectance image $r = g - l$ can be assumed to have a high prior probability. One of the simplest prior functions used for natural images assigns high probability to spatially smooth images.

(3) We can assume that the illumination continues smoothly as a constant beyond the image boundaries and we can take a Gauss filtering to obtain an initial value.

Thus, we can calculate reflectance image *r(x,y)*:

$$r(x,y) = g(x,y) - g(x,y) \bullet m(x,y,\sigma) \qquad (7)$$

$$m(x,y,\sigma) = \exp((x^2 + y^2)/\sigma^2) \qquad (8)$$

Where σ is a constant which controls the extent of mask *M(x,y)* and it should restrict *r(x,y)* to a high prior probability , and $\bullet$ represents spatial convolution. An high pass to *LL* and low pass filtering *HH* to reflectance image *r(x,y)* in wavelet domain(frequency domain) can achieve the aim of dodging to remove center/surround light and contrast distribution degrade. Figure 6 gives the dodging processing flow.

A detail image dodging processing sample based on RW model is analyzed as figure 6 shown. The sample image is an area degradation image with center/surround un-even light distribution, which is caused by imaging sensor such as camera lens' distortion as figure 7(a) shown.

In the sample dodging processing, the illumination is obtained using an *r*=5 gauss blur. Figure 7(b) is the final dodging result based on RW model to the sample image. It has a better view effect with even light and contrast distribution.

Image illumination problems are common existed in all kinds of imaging system. Figure 8 is the dodging result of some Mars images from the recent landed "Courage" cameras (Left navigation camera non-linear full frame EDR acquired on Sol 9 of Spirit's mission to Gusev Crater at approximately 13:18:01 Mars local solar time).

2.3 Image Restoration in Retinex Wavelet Domain

The purpose of image restoration is to compensate for defects, which degrade an image such as edge blur. This is different to image enhancement, which is mainly to remove additional imaging defects such as the over exposure to obtain the best view effects. The image decomposition in equation (4) for image enhancement is always understood with illumination model while for image restoration, the imaging focus model is more suitable. Thus, the estimation is different in Section 3.2. Bit slicing can segment image in 8-fixed focal panel image to differ noise, as equation (10). And bit synthesis can combine any bit image together to obtain variance focus panel image. In this paper, the bit slicing and bit operation is adopted to estimate *l(x,y)*, which is taken as imagery on focal length panel. With transcendental cognition of satellite on-orbit focus, we can use the following model to judge whether the synthetic image with different bit panel images is the imagery on focus as equation (9):

$$\frac{g}{g_f} \approx 1 \qquad (9)$$

$$g_f = \sum \forall g_i, i = 0,1,...7 \qquad (10)$$

$$g_i = g \,\&\, i, i = 0,1,...7 \qquad (11)$$

Where g is the degrade image, g_f is image on focal panel, g_i is the i bit panel image, & denotes the 'and' operation.
Once *l(x,y)* is determined, the image restoration can be easily done to *r(x,y)* in wavelet domain. There are many restoration algorithms in wavelet domain (M.R. Banham, 1996, M. Belge, 2000, Y. Wang, 1999, M. Crouse, 1998, R. Chan, 2003).

with geometric correction before mosaic. Thus, the mosaic slot is missed after this processing. We can see obviously in the 1:1 zoom windows as figure 11(c) and figure 11(d) that the mosaic slot of buildings can be effective removed. Figure 12 shows result of a mosaic project with 8 IKNOS images.

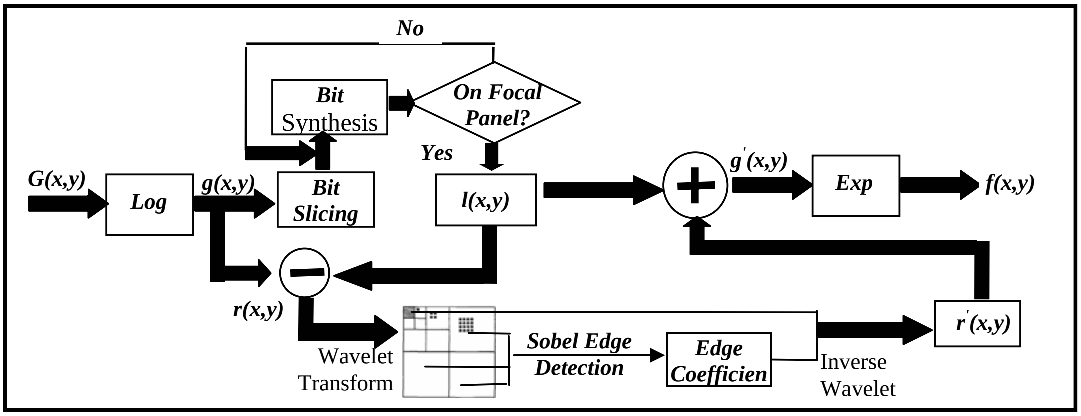

Figure 9 Restoration Based On RW Model

Considering the blur edge degradation, an edge preservation filtering to wavelet coefficients with the edge detection is proposed in this paper to do image restoration in RW domain. Figure 9 gives the total processing flow.
Sobel operator is used for edge detection to the wavelet coefficients to make edge clear and non-edge coefficients are taken as noise and removed. Furthermore, the regularized image restoration based on common imaging model as figure 1 shown can be taken to *i(x,y)* if large sensor movement exist during imaging. Figure 11 gives the restoration result based on RW model to SPOT image.

The focal panel image is composite of 3, 4, 6, 7 and 8 bits while the non-focus image is composite of 1, 2 and 5 bit. Bit 1 and bit 2 images are almost noise, while the bit 5 image is the contour image. As figure 10 (a) and (b) shown, the blur edge becomes clearer. Table 1 gives the quality assessment result of Wiener Restoration, Inverse Filtering and RW based restoration proposed in this paper.

Table 1 Image Restoration Comparison

	Wiener Restoration	Inverse Filtering	RW Based Restoration
Mean Square Gradient	5.148	5.800	9.214
Definition	0.21	0.24	0.45

As table 1 shown, the restoration result based on RW imaging model is superior to wiener restoration and wiener filtering based on the traditional imaging model as figure 1 shown.

3. EXPERIMENTS AND RESULTS

For photogrammetry and remote sensing, image mosaic is very important to produce orthodox image map. It is very common that the adjacent two images or adjacent two stripe image have different contrast and tone, which will make image mosaic fail with obvious mosaic strip as figure 12(a) shown and 'colour cloth' phenomena to high resolution satellite image as figure 13(a) shown.
In order to remove the mosaic stripe, image dodging based on RW imaging model to the adjacent two images is done together

4. CONCLUSIONS AND DISCUSSIONS

Retinex Wavelet imaging model based provides a reasonable image decomposition and representation, which is different to traditional imaging model. This model distinguish image with ill-problem part and non-ill part to avoid image quality improvement processing together damaging non-ill part and fully consider the characteristic of HSV. The image dodging enhancement to different kinds of image defects show that it can effectively deal with non-even light, contrast and tone problems. The image restoration based on RW model to blur edge is better than common restoration algorithms. The typical application of image mosaic shows the advantages of proposed RW imaging model in the field of image quality related applications. And also it can improve the image quality such as shadow defects to restore objects, which is very useful to image understanding processing such as object identification, image matching and image vision. Most important, the retinex wavelet based image representation model is a simulation of HSV and its sensitive course, which can be used for image quality assessment system. The authors think the quality assessment system based on RW imaging model can combine quantitative assessment and personal assessment standard and it will be a research direction of uniting quality assessment system. Still some other problems and researches in this work to be done in the future are listed as following items:

(1) More imaging processing algorithms based on retinex wavelet model such as image fusion, image compression and image understanding.
(2) Effective and accurate estimation of *l(x,y)*
(3) Image quality assessment based on retinex wavelet model

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Figure 7(a) Original Image with Un-even light

Figure 7(b) Result Image with Dodging Processing

Figure 7 Dodging to Sample Image

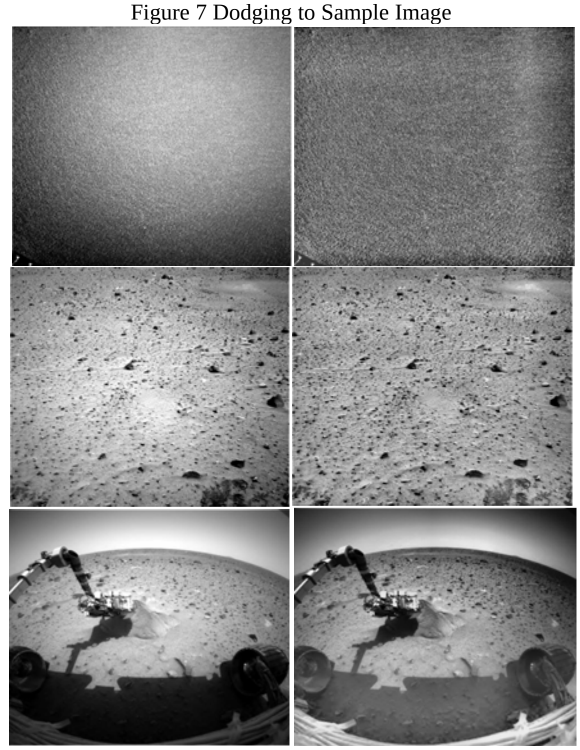

Figure 8 Mars Images Dodging

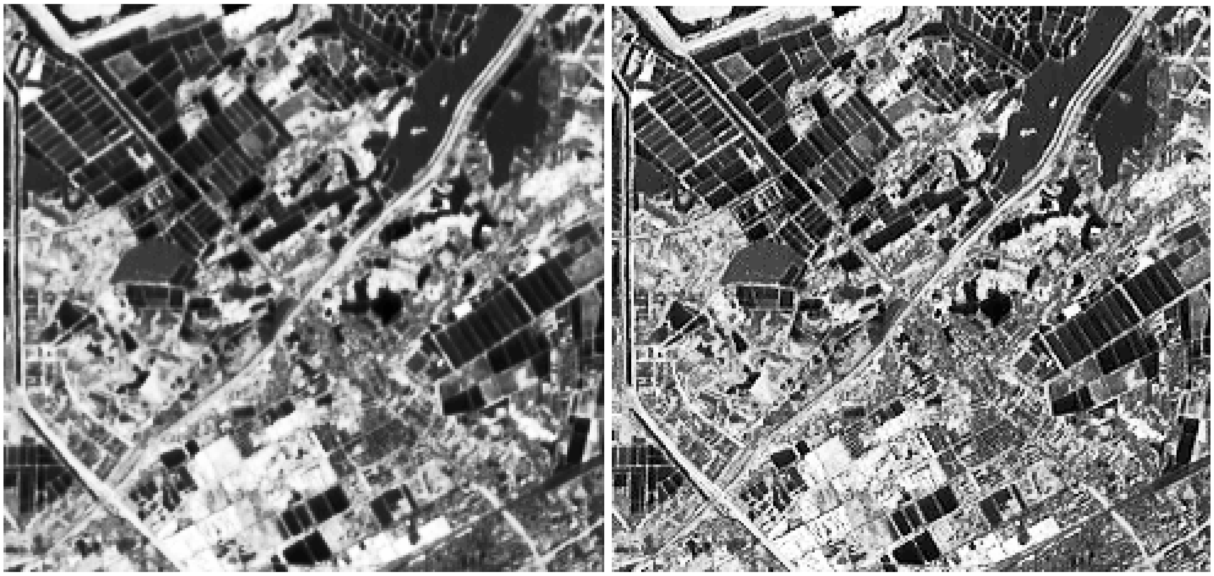

Figure 10(a) 1:1 Window of Original Image Figure 10(b) 1:1 Window of Restored Image

Figure 10 Image Restoration Based On RW Model

Figure 11(a) Mosaic without Dodging Figure 11(b) Mosaic with RW based Dodging

Figure 12 (a) Mosaic without Dodging

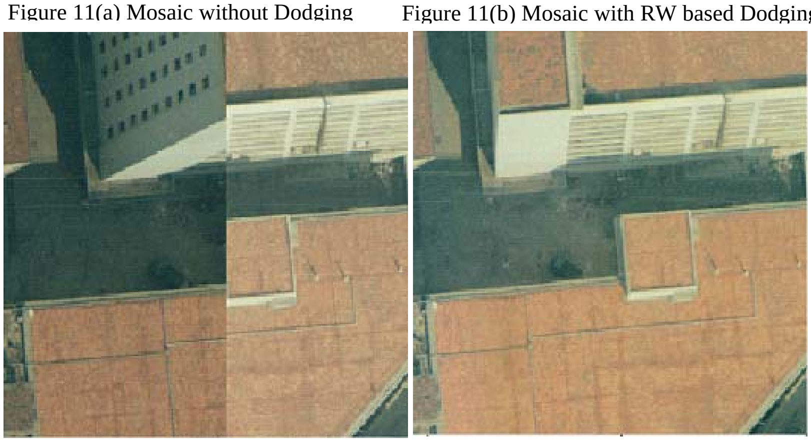

Figure 11(c) 1:1 Zoom Window of (a) Figure 11(d) 1:1 Zoom Window of (b)

Figure 11 Mosaic Result Comparisons

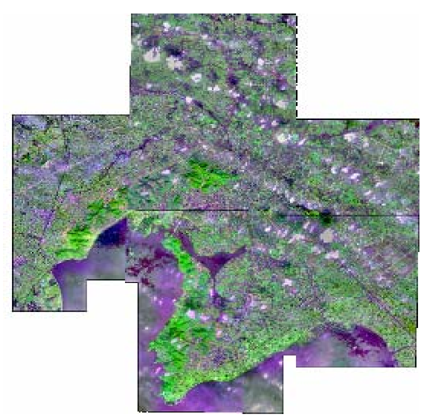

Figure 12 (b) Mosaic after Dodging

Figure 12 Comparisons to IKNOS Images Mosaic