Improved MASK dodging method based on wavelet

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Abstract: Aimed at the uneven illumination phenomena in the remote sensing image, this paper puts forward an improved MASK dodging method based on wavelet. According to the process of MASK dodging method, this method proposed improves the modulus of wavelet self-adaptively and non-linearly in the process of the background image obtaining. Finally the experiments are given, which show that this improved dodging method can avoid the disadvantages of the method using mean in blocks as the modulus of wavelet directly, and they also show that this method in this paper can resolve the uneven illumination in remote sensing image. It can be applied in many cases.

Key words: dodging method for Remote Sensing Image, MASK dodging method, wavelet transform, improved MASK dodging method

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1 INTRODUCTION

When capturing the remote sensing image, due to the factors of sensor and the outer conditions, the luminance and contrast would be different in different parts within an image. These differences make it difficult for image interpretation and mosaic. Therefore, it has an important practical application value to study and process such uneven illumination phenomenon.

At present, the methods to remove the uneven illumination phenomenon include two categories in general: The first one is to use a mathematical model to fit the luminance change within an image, and then to compensate the difference of luminance in different parts according to the fitting result (Wang & Pan, 2004), such as “Mask” technology (DMC), background simulation (Zheng, 2003), the dodging method based on self-adaptive template proposed by Zhang (2003) and Li (2005), and top-hat based on mathematical morphology. However, there are so many reasons that cause the uneven distribution of luminance within an image. Some anomaly luminance changes or isolated luminance aberrances may lead such method fail to fit the luminance change, and finally greatly affect the quality of processing. The other one is using low-pass filter, such as the MASK dodging method proposed by Wang and Pan (2004), Li (2006), etc. This kind of method uses an appropriate low-pass filter to get the background image with uneven illumination phenomenon, and then the result image will be obtained by subtracting the background image from original image. This method does not need the concrete luminance function, so it has great practicability. However, how to choose a proper filter is a difficult problem.

Since the wavelet has the characteristic in both the spatial domain and the frequency domain, using wavelet transform as low-pass filter to remove the background image can receive good effects. Based on the MASK dodging principle, this paper introduces how to use wavelet transform to remove the background image. Finally an improved MASK dodging method based on wavelet is proposed. The examples show that this method can get an excellent dodging effect.

2 THE MASK DODGING PRINCIPLE BASED ON WAVELET TRANSFORM

2.1 The MASK dodging principle for single image

The MASK dodging technique was presented to deal with optical photos when printing off. Based on the MASK dodging principle, the following formula can depict the mathematical model for images with uneven illumination phenomenon:

$$I'(x,y) = I(x,y) + B(x,y) \tag{1}$$

where $I'(x, y)$ denotes image with uneven illumination phenomenon, $I(x, y)$ denotes image in ideal conditions, and $B(x, y)$ denotes background image. According to Eq.(1), image with uneven illumination phenomenon can be regarded as the result of overlapping an ideal image with a background image. So the uneven background is the reason for an image with uneven illumination phenomenon. If background image can be fitted well, image with even illumination can be obtained by subtracting background image from original one, and then the uneven illumination phenomenon can be removed (Wang & Pan, 2004).

How to get the background image is very important. In the frequency domain, the luminance changes in overall image can

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be reflected mainly by the low-frequency components. So the approximate background image can be acquired by low pass filter (Pilu & Pollard, 2002). Then, It is critical to choose an appropriate low-pass filter to use it to obtain a good background image. In general, a better filter has both small spatial position error and small frequency domain error. Considering the good characteristic of wavelet as well as its low calculation and small error, this paper uses wavelet as low-pass filter to obtain the background image.

2.2 Remove the background image using wavelet transform

Wavelet transform developed from Fourier transform. Because of its multi-resolution analysis and excellent frequent characteristic, wavelet transform can make up the shortcoming of Fourier transform in many case of digital image processing.

After wavelet decomposition, the spatial distribution of coefficient has excellent parallelism with original spatial distribution of image. Based on the multi-resolution analysis of wavelet, we can remove all the coefficient of high-frequency and reserve the coefficient of low-frequency in the N^{th} layer, and then reconstruct the wavelet. Finally the detail information is removed and the background with luminance changes is reserved. The processing flow is depicted in Fig. 1.

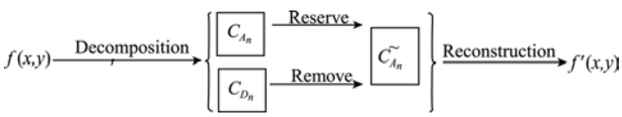

Fig. 1 Filter to get background image based on wavelet transform

In order to obtain a good background image, we need to deal with the coefficient of low-frequence in some degree. Wang and Long (2005) have proposed a method to deal with the wavelet coefficient, there is the process as follows:

(1) Divide the original image to $2^n \times 2^n$ small parts. And estimate the intensity of every part using the mean in it, so an imprecise small image will be get, which size is the $1/(2^n \times 2^n)$ of original image.

(2) Wavelet decomposition of *n* layers will go on to original image. And replace the wavelet coefficient in low-frequence with the estimated value in Step (1), then set all coefficient in high-frequence to zero. Finally restructure the wavelet to get the background image.

(3) Subtract the background image from the original image, and adjust the brightness and contrast appropriately.

The disadvantage of this method is that the estimate value after divided has great distinction from the low-frequent coefficient of wavelet after decomposition, which lead to the background image not perfect. And it can not reflect the luminance changes completely. So this paper improved the method by stretching the coefficient of low-frequent adaptively to get the better dodging effect.

2.3 The improved MASK dodging method based on wavelet transform

Considering the disadvantage of the method above, this paper improved it as follows:

(1) Still divide the original image to $2^n \times 2^n$ small parts. But regard the mean of every part as the rude estimate value of low-frequent coefficient after wavelet decomposition of *n* layers, and then stretch the estimate value nonlinearly and adaptively, the formula is as follows:

$$\begin{cases} Y=\delta e^{A(x)}, & x<\text{Average} \\ Y=e^{A(x)}\big(A(x)-A(x_0)\big)+\ln C_{\min}, & x\geqslant\text{Average} \end{cases} \quad (2)$$

where,

$$A(x)=\frac{\ln C_{\max}-\ln C_{\min}}{x_{\max}-x_{\min}}(x-x_{\min})+\ln C_{\min} \quad (3)$$

And x_0=Average in Eq.(3); Average stands for the average gray value of original image, $C_{\max}$ and $C_{\min}$ are the maximal and minimal value of low-frequent coefficient after wavelet decomposition respectively, $x_{\max}$ and $x_{\min}$ are the maximal and minimal gray value of original image respectively, and x is the transformed value, which is also the mean value of every small part of process (1). And δ is the parameter of stretching. This paper has given an experimental value for it, which can be adjusted for users.

Then set all the coefficient in high-frequence to zero. Finally restructure the wavelet to get the background image.

(2) After subtracting the background image from the original image, we take Eq. (4) (Wang & Pan, 2004) to stretch the overall contrast and to increase the adjacent fine contrast.

$$f_{\text{out}}=\begin{cases} \dfrac{255\times(f_{\text{in}}-\text{value})}{255-2\times\text{value}}, & \text{value}>0 \\ \dfrac{f_{\text{in}}\times\big(255+2\times\text{value}\big)}{255}-\text{value}, & \text{value}<0 \end{cases} \quad (4)$$

In Eq.(4), *value* is the parameter of contrast stretching. Its value ranges from −127 to 127.

After improving, the coefficient of original wavelet is stretched adaptively, therefore, background image can both fit the luminance change and remove most detail information of original image. Finally the excellent effect can be obtained.

A method to deal with color image is from RGB channels respectively. However, maybe this method will result in the distortion of tone. So, this paper transforms the *RGB* space to HIS space, and deal with the embranchment of luminance “*I*” only in order to keep the color information.

3 RESULTS

To find an objective and uniform estimate criterion to the results is still an unresolved problem. It highly requires human’s subjectivity. A good result needs a clear image, moderate contrast, keeping the average luminance and main tone of local image, and keeping as much information as possible. In order to test the advantage of the proposed method, this paper chooses a remote sensing image with uneven illumination, and analyses the effect in both visual aspect and qualitative aspect.

(1) In visual aspect: this paper mainly adopts visual interpretation method. Observing the distribution of luminance based on human visual system, and analyses the effect subjectively. The dodging experiment is shown in Fig. 2. Fig. 2(a) shows the image with uneven illumination, Fig. 2(b) shows the result of the unimproved method, and Fig. 2(c) shows the result using improved method.

From Fig. 2(a), we can see that it has obvious uneven illumination phenomenon, the left-upper part is brighter than the right-lower part; Fig. 2(b) has improved in some degree for vision, but doesn't remove the uneven illumination phenomenon completely. However, the proposed method shown in Fig. 2(c) almost removes the uneven illumination phenomenon, and the image is clearer.

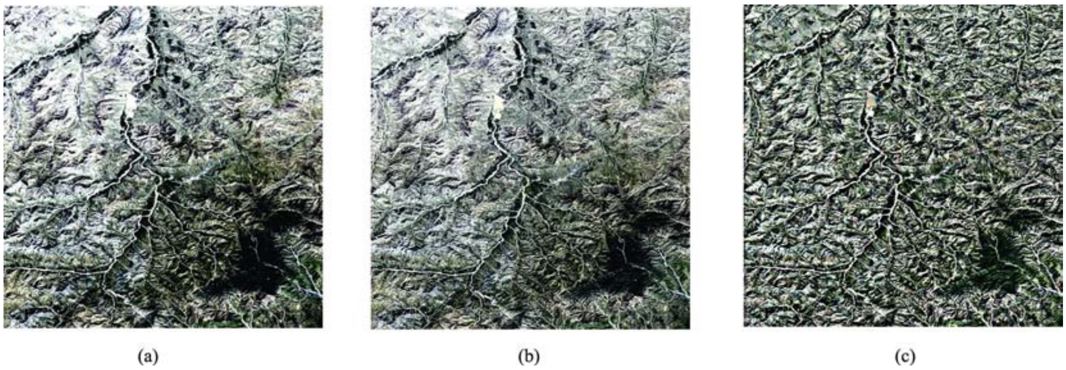

Fig. 2 The dodging experiment
(a) The original image; (b) The result of the unimproved method; (c) The result of the improved method (δ=1.5)

(2) In qualitative aspect: we considered both the mean and the average gradient in order to describe the quality of image.

The mean stands for the luminance information, and average gradient stands for detail contrast and the character of texture change. The ideal image should increase the average gradient slightly, but not excessively.

The average gradient adopts the following formula (Li & Guan, 2000):

$$\nabla\overline{G}=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[\Delta_x f(i,j)^2+\Delta_y f(i,j)^2]^{1/2} \tag{5}$$

where, $\Delta_x f(i,j)$ and $\Delta_y f(i,j)$ denote the difference of first order in x and y direction respectively.

In order to validate the dodging effect, Table 1 compares the mean of every channel and the average gradient in four local parts of Fig. 2(a), (b) and (c).

From the statistical data in Table (1), it is obvious that the left upper part in Fig. 2(a) has big value of mean, but the right lower has small value. That is to say, Fig. 2(a) has obvious uneven illumination phenomenon. The unimproved method has better effect than original image in some degree, but still has uneven illumination phenomenon; And the improved method shows that the mean in every part has improved obviously, the luminance is almost even. At the same time, the average gradients of each part and the entire image increase a little, which shows that using improved method, the adjacent fine contrast and overall contrast of image are all enhanced in a certain extent.

Table 1 The quality of the images

Part	Channel	Mean			Average gradients		
		Fig.2(a)	Fig.2(b)	Fig.2(c)	Fig.2(a)	Fig.2(b)	Fig.2(c)
Left upper	*R*	167.04	159.85	139.70	37.55	38.44	40.25
	G	176.83	168.85	151.07	36.93	37.31	39.42
	B	173.93	165.94	143.35	36.77	37.50	38.46
	I	172.60	164.88	144.71	37.08	37.75	39.38
Right upper	*R*	149.99	146.45	136.06	41.19	42.27	44.68
	G	160.43	156.20	147.32	40.76	41.36	44.08
	B	152.51	149.24	139.26	40.62	41.55	43.01
	I	154.31	150.63	140.88	40.86	41.73	43.92
Left lower	*R*	120.49	123.33	130.01	44.05	44.99	46.09
	G	133.28	135.03	141.07	43.79	44.38	45.34
	B	126.19	128.65	134.43	43.62	44.47	45.23
	I	126.65	129.00	135.17	43.82	44.61	45.55
Right lower	*R*	83.31	94.26	118.27	39.80	40.73	42.91
	G	94.01	104.48	130.61	39.96	40.69	42.90
	B	85.75	97.26	122.94	39.18	40.14	41.64
	I	87.75	98.67	123.94	39.65	40.52	42.48
Overall	*R*	131.16	131.72	131.26	40.71	41.67	43.86
	G	142.09	141.88	142.75	40.41	40.98	43.23
	B	135.66	136.07	135.23	40.10	40.97	42.10
	I	136.30	136.89	136.41	40.41	41.21	43.06

4 CONCLUSIONS

The theory analysis and experiments show that the improved method has obvious advantage to unimproved dodging method:

(1) The uneven illumination phenomenon has been removed, and it makes the need of visual interpretation.

(2) Based on maintaining the average luminance and tone, the information of texture and details has been increased by using the method proposed in this paper. And it has advantage to the further processing of image.

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小波变换改进的MASK匀光算法

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摘 要: 针对单幅遥感影像内部所产生的亮度不均匀现象, 提出了一种基于小波变换改进的MASK匀光算法。该方法在利用小波变换获得不均匀背景图像的过程中, 对小波系数进行了自适应非线性改进, 克服了直接利用分块取均值获取背景影像的不足, 试验表明该算法能够较好地解决单幅遥感图像中亮度不均匀的现象, 具有较强的实用性。

关键词: 遥感影像匀光方法, Mask匀光方法, 小波变换, 改进的Mask匀光方法

中图分类号: TP751.1 文献标识码: A

1 引 言

在遥感图像获取的过程中, 由于传感器本身以及光照条件的影响, 导致获取的影像在亮度和反差上存在着不同程度的差异, 这些差异给图像判读分析以及镶嵌等带来了很大的困难。为了消除影像的这些差异, 需要对获取的影像进行匀光处理, 消除亮度及反差的差异, 提高影像的实用价值。

目前单幅遥感影像的匀光方法大体分为两类: 一是利用数学方法模拟影像亮度变化, 然后再对影像不同部分进行不同程度的补偿, 从而获得亮度、反差均匀的影像(王密 & 潘俊, 2004)。如"掩模"技术(DMC), 背景模拟法(郑军等, 2003), Zhang 等(2003)、李治江等(2005)提出的基于自适应模板的匀光算法以及基于数学形态学的top-hat变换法等。但是, 由于影像的亮度分布、变化的不规则性以及局部亮点的存在会使亮度背景模拟失败, 对于这类方法, 最终得不到好的匀光效果。第二类是低通滤波法。如王密和潘俊(2004)、李德仁等(2006)提出的基于MASK原理的匀光处理方法等。该类方法选择适当的滤波器对原图像进行低通滤波, 得到反映亮度变化的背景影像, 然后将其从原始影像中减去, 得到亮度均匀的影像。由于此方法不需要知道具体的光照函数, 因此具有很强的实用性, 但如何选择合适的滤波器一直是一个难题。

根据小波既考虑空域又兼顾频域的特性, 利用小波变换进行低通滤波滤除背景影像, 能够收到好的匀光效果。

2 基于小波变换的MASK匀光原理

2.1 单幅影像的MASK匀光原理

MASK匀光法是针对光学像片的晒印提出来的。按照其匀光原理, 对于光照不均匀的影像可采用如下数学模型进行描述:

$$I'(x,y)=I(x,y)+B(x,y) \tag{1}$$

式中, $I'(x, y)$表示亮度不均匀的影像; $I(x, y)$表示理想条件下亮度均匀的影像, 也就是通过匀光处理后希望获得的影像; $B(x, y)$表示背景影像。按照公式(1), 亮度不均匀的影像可以看作是亮度均匀的影像叠加一个背景影像的结果, 而亮度不均匀可认为就是背景影像造成的, 因此如果能够很好的模拟出背景影像, 将其从原始影像中减去, 然后进行拉伸处理增大相邻细部反差就可以消除单幅影像的亮度、反差不均匀现象(王密 & 潘俊, 2004)。

背景影像的获取至关重要。从频率域的角度来说, 代表影像色调和亮度变化的部分位于低频, 因此低通滤波后的影像可以近似地看作背景影像(Pilu & Pollard, 2002)。那么, 能否找到好的滤波器直接关系到匀光效果的好坏。通常情况下, 好的滤波器既要有小的空域误差又要有小的频域误差, 考虑到小

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波函数既兼顾到频域又兼顾到空域，具有计算量小、频域、空域误差相对小的优点，故借助小波变换进行低通滤波得到背景影像。

2.2　利用小波变换滤除不均匀背景影像

小波是在傅里叶变换分析的基础上发展起来的，由于小波变换的多分辨率分析和它良好的频率特性，在数字图像处理的很多领域弥补傅里叶变换的不足，并且实现较好的滤波效果。

小波分解后，小波系数的空间分布同原始图像的空间分布具有很好的对应关系，利用小波的多分辨率特性，可将图像先进行 n 层小波分解，然后将分解后得到的高频系数滤除，保留低频系数，最后再进行 n 层小波重构，这样就去除了细节信息，保留了代表影像亮度的背景信息。具体流程如图 1。

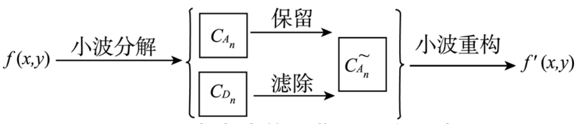


图 1　小波滤波获取背景影像示意图

为了得到好的背景影像，不能单纯的保留低频系数，而是要对低频系数作一定的处理。王宇和龙兴武(2005)提到了一种对小波系数处理的方法，其具体步骤是:

(1) 将原始图像分解成大小为 $2^n\times2^n$ 的子块。利用每个子块中像素的平均灰度值对本块的光照强度作一个估计，得到一个大小是原图的 $1/(2^n\times2^n)$的粗略估计图。

(2) 对原始图像进行 n 层小波分解。将分解后的小波低频系数用上述得到的估计值代替，并将所有的高频系数置零。然后进行 n 阶小波重构，得到背景影像。

(3) 从原始图像中减去背景影像并适当调节亮度和对比度。

这种方法的不足之处在于分块后取得的均值可能与小波分解后的低频系数差别较大，导致得到的背景影像明暗不清晰，也就是背景影像并非最佳，这样在相减过程中导致了原图中过亮的地方仍然过亮，匀光的效果不明显。因此本文在此基础上将其进行自适应改进，对此小波系数做自适应非线性拉伸，这样就更好的描述了背景影像，从而得到更好的匀光效果。

2.3　基于小波变换改进的 MASK 匀光算法

针对上述方法的不足，本文作了如下改进:

(1) 仍然将原始图像分解成大小为 $2^n\times2^n$ 的子块，并以每个子块的平均灰度值作为小波 n 层变换后低频系数的粗略估计值，然后将这个粗略估计值进行自适应非线性拉伸，拉伸函数如公式(2):

$$\begin{cases} Y=\delta \mathrm{e}^{A(x)}, & x<\text{Average} \\ Y=\mathrm{e}^{A(x)}\big(A(x)-A(x_0)\big)+\ln C_{\min}, & x\geqslant \text{Average} \end{cases} \tag{2}$$

其中，
$$A(x)=\frac{\ln C_{\max}-\ln C_{\min}}{x_{\max}-x_{\min}}(x-x_{\min})+\ln C_{\min} \tag{3}$$

式中，x_0=Average; Average 代表原始图像灰度均值; $C_{\max}$表示小波分解后小波低频系数最大值; $C_{\min}$表示小波分解后小波低频系数最小值; $x_{\max}$表示原始图像灰度最大值; $x_{\min}$表示原始图像灰度最小值; x为待变换值，即经过步骤(1)提取出的每小块均值; δ为拉伸参数，本文给出了实验的一个经验值，在实际操作中可作为一个匀光参数供用户调节。

同时令第一至第 n 层的细节系数都为零。再作 n 次小波反变换得到背景图像。

(2) 从原始影像中减去背景图像后，采用公式(4)进行适当的对比度拉伸(王密 & 潘俊, 2004)，增大邻部反差。

$$f_{\text{out}}=\begin{cases} \dfrac{255\times(f_{\text{in}}-\text{value})}{255-2\times\text{value}}, & \text{value}>0 \\ \dfrac{f_{\text{in}}\times\big(255+2\times\text{value}\big)}{255}-\text{value}, & \text{value}<0 \end{cases} \tag{4}$$

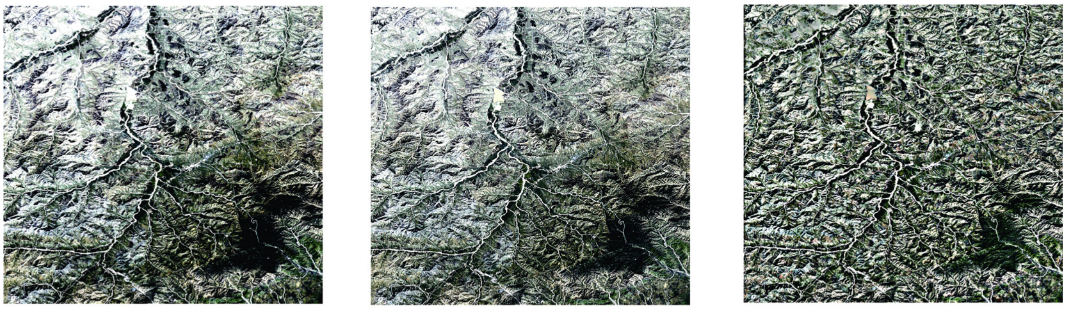
式中，value 为对比度拉伸参数，取值范围为(–127, 127)。

这样改进后，原有的小波系数得到了自适应拉伸，使得背景图像即能够很好的表达色调和亮度信息，又不带有过多的细节信息，最终得到好的匀光效果。

对于彩色图像，可以采用分通道处理的方法，但有时会造成处理后颜色的失真，本文将 R, G, B 颜色空间转换到 HIS 色彩空间，仅对亮度分量 I 进行处理，以保证处理后的图像颜色不失真。

3　实验与分析

对于影像匀光处理结果的评价问题始终没有一个统一的客观评价标准，它对人的主观判读要求很高，要做到好的处理结果，需要影像清晰，反差适中，尽量保持原影像的平均亮度和平均色度，而且尽可能保证原始影像信息不丢失(杨文久 & 刘心季, 1994)。为了验证本算法的优越性，选取了一幅亮度不均匀的遥感影像，从视觉和定量两个方面对其进行分析(试验结果如图 2)。



(a) (b) (c)

图 2 实验结果

(a)为原始图像; (b)利用改进前算法处理后的结果; (c)为采用改进后算法处理后的结果(δ=1.5)

(1) 视觉方面: 主要是通过目视判读的方法, 以人的视觉系统观测影像的亮度分布情况, 以主观鉴别匀光处理的效果。在实验中, 图 2(a)是原始的亮度不均匀的影像, 图 2(b)是利用改进前算法处理后的影像, 图 2 (c)是用改进后算法处理后的影像。

从图 2(a)可以看出, 图像明显的存在亮度不均匀现象, 左上方明显偏亮, 而右下方明显偏暗; 从视觉上看, 图 2(b)虽然较原始影像有所改进, 但依然存在亮度不均匀的问题, 左上方亮度依旧较亮, 右下方亮度依旧较暗; 采用本文的算法(图 2(c)), 亮度不均匀的情况几乎不存在, 色调变得均匀, 而且影像更加清晰。

(2) 定量方面: 为了描述图像的质量, 我们同时考虑影像的均值和平均梯度。

均值代表了影像的亮度信息, 平均梯度表示影像微小细节反差和纹理变化特征, 处理后的理想图像较原图像平均梯度稍有增加, 而不过分增大。

平均梯度采用下列公式(李德仁 & 关泽群, 2000):

$$\nabla\bar{G}=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[\Delta_x f(i,j)^2+\Delta_y f(i,j)^2]^{1/2} \qquad (5)$$

式中, $\Delta_x f(i,j)$, $\Delta_y f(i,j)$ 分别为像素(i, j)在 x 方向和 y 方向上的一阶差分值。

为了验证图像的匀光效果, 本文将图像整体平均划分为 4 块, 分别求取它们的 R, G, B 均值和亮度均值 I 以及平均梯度。

从表 1 统计数据的亮度均值可以看出, 原图像数据图 2(a)左上方亮度值明显偏高, 而右下方亮度值偏低, 存在明显亮度不均匀现象。利用未改进算法图 2 (b), 各局部均值较原图像都有所改善, 但左上方与右下方亮度均值之差仍然较大, 说明仍旧没有消除区域上的亮度不均匀现象; 而改利用改进后算法图 2 (c), 图像各局部均值有了明显改进, 各部分的亮度均值之差是 3 幅图像中最小的, 亮度基本达到了均衡。同时, 从平均梯度上分析, 图 2(b)较图 2(a)变化不大, 而图 2(c)比图 2(a)和图 2(b)略有提高, 这说明改进后的算法结果无论是相邻细部还是整体, 反差都有所增强, 影像的清晰程度也相对较高。

表1 影像质量统计数据表

局部	通道	均值			平均梯度		
		图2(a)	图2(b)	图2(c)	图2(a)	图2(b)	图2(c)
左上	R	167.04	159.85	139.70	37.55	38.44	40.25
	G	176.83	168.85	151.07	36.93	37.31	39.42
	B	173.93	165.94	143.35	36.77	37.50	38.46
	I	172.60	164.88	144.71	37.08	37.75	39.38
右上	R	149.99	146.45	136.06	41.19	42.27	44.68
	G	160.43	156.20	147.32	40.76	41.36	44.08
	B	152.51	149.24	139.26	40.62	41.55	43.01
	I	154.31	150.63	140.88	40.86	41.73	43.92
左下	R	120.49	123.33	130.01	44.05	44.99	46.09
	G	133.28	135.03	141.07	43.79	44.38	45.34
	B	126.19	128.65	134.43	43.62	44.47	45.23
	I	126.65	129.00	135.17	43.82	44.61	45.55
右下	R	83.31	94.26	118.27	39.80	40.73	42.91
	G	94.01	104.48	130.61	39.96	40.69	42.90
	B	85.75	97.26	122.94	39.18	40.14	41.64
	I	87.75	98.67	123.94	39.65	40.52	42.48
整体	R	131.16	131.72	131.26	40.71	41.67	43.86
	G	142.09	141.88	142.75	40.41	40.98	43.23
	B	135.66	136.07	135.23	40.10	40.97	42.10
	I	136.30	136.89	136.41	40.41	41.21	43.06

4 结　论

理论分析与实验研究表明经过自适应改进后的匀光算法, 较改进前的匀光算法具有更明显的优点:

(1) 在视觉上, 消除了影像亮度和反差的不均匀现象, 达到了匀光、匀色的目的, 便于目视判读。

(2) 从信息量上, 本文算法能够在保证不偏离原始图像平均亮度和色度的基础上, 增加了纹理和细节信息, 更有助于图像的后处理。

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