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Multispectral and Panchromatic Images Fusion Based on Integrating Feedback Retina and IHS Model

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***Abstract*— In this paper, we present feedback retina model combined with IHS model for fusion of multispectral (SPOT) and panchromatic (IKONOS) images. Multispectral images are limited by low spatial resolution. So, combining of low-resolution multi-spectral and high-resolution panchromatic images is a way for improving the spatial quality of multispectral images. An ideal fusion process preserves the original functional characteristics and adds spatial characteristics to the image with no spatial distortion. The intensity-hue-saturation (IHS) algorithm and the feedback retina model fusion technique can maintain more spatial feature and more functional information content, respectively. The presented algorithm integrates the advantages of both fusion methods to enhance the information content. Visual and statistical analyses show that the proposed algorithm significantly improves the fusion quality in terms of discrepancy, and average gradient; compared to fusion methods including, IHS, Brovey, discrete wavelet transform, a-trous wavelet and Non-feedback retina model.**

***Index Terms*—Image fusion, Feedback retina model, Multi-spectral, Panchromatic, Remote sensing**

I. Introduction

REMOTE sensing is a science with applications in urbanism, surveillance and military. The term of “Remote sensing” is used to describe the science of identifying, observing, measuring an object or collecting data about an object from a distance. This process involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, by which they may be identified and categorized by class/type, substance, and spatial distribution. Humans do this task with aid of eyes or by the sense of smell or hearing. Earth scientists use the technique of remote sensing to monitor or measure phenomena.

Remote sensing of the environment is usually done with using of mechanical devices known as remote sensors. These devices have a greatly improved the capability to receive and record information about an object without any physical contact. Most sensing devices record information about an object by measuring transmission of electromagnetic energy from reflecting and radiating surfaces of an object. Remote sensing imagery has many applications in mapping land-use and cover, agriculture, soils mapping, city planning, military observation, and etc.

The sensors, that acquire the images, can acquire information in different spectral bands on the basis of the exploited frequency or at different resolutions. Therefore, a broad spectrum of data can be acquired from the same observed object or scene. For many applications the information provided by one sensor is incomplete, inconsistent, and imprecise [1].

Image fusion is the process of integrating information from two or more images of an object or scene into a single image that is more informative and appropriate for visual perception or computer analysis. The purpose of image fusion is to decrease ambiguity and minimize redundancy in the output while maximizing the relative information specific to an application [2]. The limited spatial resolution has often enabled little morphologic information to be obtained from SPOT (Satellite Pour l'Observation de la Terre) images, making investigations difficult to interpret. The SPOT satellite is multispectral, capturing green, red, and reflected infrared bands at 20x20 meters. IKONOS is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. Integrating low-resolution multi-spectral (SPOT) and high-resolution panchromatic (IKONOS) images is a helpful technique to improve both qualitative detection and quantitative determination in remote sensing investigations is expected to provide much more information [3].

In recent decays a variety of image-fusion techniques have been developed to fuse Multi-spectral (MS) and Panchromatic (PAN) images which exhibit complementary characteristics of spatial and spectral resolutions. Among the fusion methods, the multi-resolution fusion techniques have been discussed most frequently in the recent publications due to its profits over other fusion techniques [4,5]. Therefore, this study focuses on the new model of multi-resolution fusion methods. The non-feedback retina based fusion technique can better preserve the spectral and spatial information than the other conventional methods do [6]. This technique extracts spatial detail information from a high-resolution PAN image first, and then injects the spatial information into the MS bands, respectively. In this manner, the spectral distortion can be reduced. However, the spatial detail information extracted from a high-resolution PAN image is not equivalent to that of existing in an original high-resolution MS band. This difference can also introduce spectral distortion into the fusion result, especially when

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IKONOS and SPOT images are fused. Further, the spatial detail is injected into individual MS bands, then, the fused image sometimes appears like a fusion result through a high-pass filtering process, e.g., the integration between spectral and spatial detail is not smooth. Some ring effects may appear in the image, and small objects may not obtain spectral information. It is desirable that the procedure for merging high-resolution PAN data with low-resolution MS data preserves the original spectral characteristics of the later as much as possible. The procedure should be optimal in the sense that only the additional spatial information available in higher resolution data is imported into the MS bands. To overcome the drawbacks of the non-feedback retina technique, and to explore a more effective way to fuse IKONOS and SPOT images, a combination of feedback retina model and IHS model has been developed in this study. This allows the use of high-resolution PAN image while conserving the spectral properties of the original low-resolution MS images.

Visual and statistical analyses show that the proposed feedback retina model significantly improves the fusion quality compared to conventional fusion techniques.

II. RETINA MODEL

A. Non-feedback retina model

The insight into how the human visual system contrasts and combines information from different spectral bands provides one example of a working MS fusion system. The energy packing the spectral features are distributed in the lower frequency subbands, and the spatial features, edges, are distributed in the higher frequency subbands. By adding the high-scale spatial features (extracted from a PAN image) to the low-scale spatial features (from MS image), the visual-channels procedure enhances the MS images. The final cone output *cone*[r] is described in [9] where I_P represents high resolution PAN image.

The horizontal cell output *horz*[r]could be given as the convolution of the MS signals (I_M) with a Gaussian spatial filter.

$$F[r] = cone[r] - horz[r] = I_P[r] * G(r;\sigma_c) - I_M[r] * G(r;\sigma_s)$$
$$cone[r] = I_P[r] * G(r;\sigma_c)$$
$$horz[r] = I_M[r] * G(r;\sigma_s)$$
$$G(r;\sigma) = \frac{1}{2\pi\sigma^2}\exp\frac{-|r|^2}{2\sigma^2}$$

where α_c and α_s are weighting of centre and surrounding inputs and G_{σ_c} and G_{σ_s} are normalized filters (meaning a spatial integral of one) that represent the filtering of the visual sequence taking place respectively in light receptors (G_{σ_c}, or center signal) and in horizontal cells (G_{σ_s}, or surrounding signal). Both filters are spatially low-pass. Filter G_{σ_s} is more low-pass than G_{σ_c}, meaning $\sigma_S > \sigma_c$.

This allows generating a spatially enhancing MS image *F*[r], by adding the high resolution spatial features (I_P[r]) to I_M[r] [8-10].

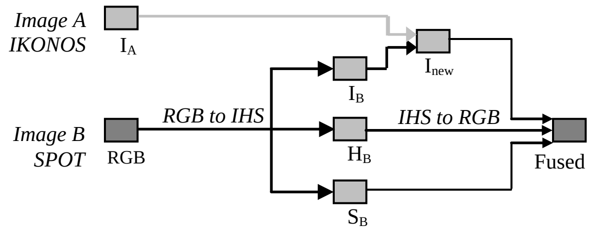

Figure 1. Diagram of IHS based fusion

B. Feedback retina model

The horizontal cell not only provides the low-scale spatial features, but also serves as a feedback path allowing the horizontal cell signal to influence the cone output. The effect of this feedback path on the cone sensitivity has already been described in the transduction stage. In addition to this, the horizontal cell signal imparts a small inhibitory influence on the cone signal.

Such inhibitory feedback effects have been modeled by several researchers. We use the simplest approach here. The weighted horizontal cell signal is simply subtracted from the cone output. The strength of this feedback path was chosen experimentally to be k_{hc}=0.15. The new enhanced MS image F^*[r] is described by below equation.

$$F^*[r] = cone[r] - horz_2[r] = I_P[r] * (G(r;\sigma_c) - k_{hc}G(r;\sigma_s)) - I_M[r] * G(r;\sigma_s)$$
$$cone[r] = I_P[r] * G(r;\sigma_c) - k_{hc}horz_1[r]$$
$$horz_1[r] = I_P[r] * G(r;\sigma_s)$$
$$horz_2[r] = I_M[r] * G(r;\sigma_s)$$

where I_P and I_M represent high resolution PAN image and low resolution MS image, respectively.

C. IHS fusion technique

The IHS spectral transform can successfully convert a multispectral image with red, green and blue channels (RGB) to IHS spectral space. Among the benefits of IHS transform operations is the ability to affect each IHS component independently, without disturbing the others. This property may be used for the fusion of multi-sensor images. The intensity displays the brightness in a spectrum, the hue is the property of the spectral wavelength, and the saturation is the purity of the spectrum.

An intensity image of the IHS system usually looks like a panchromatic image and this characteristic is used in the image fusion process. The fundamentals of IHS fusion, in summary, are: (1) align the input multispectral image to the panchromatic image if needed; (2) transform the input multispectral image from RGB to IHS color space; (3) substitute the intensity component by a panchromatic image with a higher spatial resolution; and (4) transform the substituted intensity part and original hue and saturation components by reversing to RGB color space (Figure 1) [11]. This process leads to a fused and enhanced spectral image.

Transferring a spectral image from the RGB space to the IHS space is explained by the following equations:

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$$\begin{pmatrix} I \\ v1 \\ v2 \end{pmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & \frac{-2}{\sqrt{6}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & 0 \end{bmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix},$$

$$H = \tan^{-1}\left(\frac{v1}{v2}\right),$$

$$S = \sqrt{v1^2 + v2^2} \quad .$$

where *v1* and *v2* are the transitional values in the above equations. The inverse transformation is described as:

$$v1 = S\sin(H) \quad ,$$

$$v2 = S\cos(H) \quad ,$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{6}} & \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{-2}{\sqrt{6}} & 0 \end{bmatrix} \begin{pmatrix} I \\ v1 \\ v2 \end{pmatrix}$$

III. THE PROPOSED MODEL

Because the high-resolution spatial information from an IKONOS panchromatic image is introduced into low-resolution SPOT multi-spectral, the feedback retina-inspired image fusion usually can better preserve spectral information than other conventional fusion methods [3].

The spectral intensity of the final images that are achieved from IHS fusion is high. Due to the low correlation between the SPOT intensity image and the INKONOS panchromatic image, the spectral distortion is considerable. However, the spatial details from a panchromatic image are often different from those of a multi-spectral band having the same spatial resolution and some spectral distortion is injected into the retina-inspired fusion results and the combination of spectral and spatial detail come into view abnormal. To improve the IHS and the feedback retina-inspired fusion and to overcome the deficiencies of the two methods, an integrated fusion method is proposed in this paper. The proposed method employs the IHS model transform to integrate the low-resolution spectral information (SPOT image) with the panchromatic spatial detail information (IKONOS image). Therefore, the fusion process generates a new panchromatic image that is highly correlated to the intensity image. This new image contains the spatial detail of the panchromatic source image.

According to this method, in the first stage, the multi-spectral image is transformed into the IHS triangular model components. The multi-spectral SPOT image should be aligned to the IKONOS image before the IHS transforms. Then histogram matching is applied to match the histogram of the panchromatic image to the intensity component and to achieve a new panchromatic image (Stage two). The third stage is performed by combining the new panchromatic image and original intensity image using feedback retina-inspired fusion method. In this stage a new intensity image is obtained, which contains the same spatial detail of the original panchromatic image and has similar grey value distribution to that of the intensity image of IHS transform. Ultimately, this process is completed by transforming the new intensity and the old hue and saturation components back into RGB space.

(a)

(b)

Figure 2. Original panchromatic (a) and multispectral (b) images.

IV. EXPERIMENTAL RESULTS

The test data consist of three multispectral SPOT images and high resolution IKONOS images. The spatial resolution of IKONOS images are 3350*3350 pixels (1m) and SPOT images are 168*168 pixels (20m). All dataset images are registered. Figure (2) shows an example of these images.

A good fusion scheme should preserve the spectral characteristics of the source multispectral image as well as the high spatial resolution characteristics of the source PAN image. Figure (3) shows the results of proposed method and fusion methods including, IHS, Brovey, a-trous wavelet and Non-feedback retina model. In this paper, two evaluation criteria are used for quantitative assessment of the fusion performance. The spectral quality of a fused image can be measured by the discrepancy D_k at each band [12-13]:

$$D_k = \frac{1}{P.Q}\sum_{x=1}^{P}\sum_{y=1}^{Q}\left|F_k(x,y) - L_k(x,y)\right|,$$

$$k = R, G, B,$$

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where $F_k(x,y)$ and $L_k(x,y)$ are the pixel values of the fused and original mutispectral images at position (x,y), respectively. A small discrepancy implies a good fusion result. For the spatial quality, we use the average gradient to evaluate the performance of the fused image F. That is:

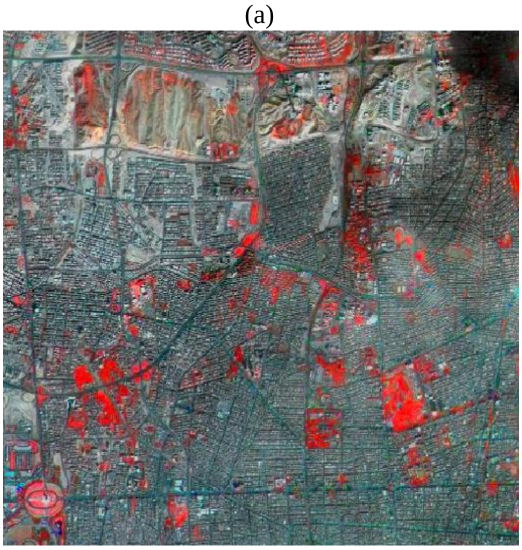
$$ag_k = \frac{1}{(P-1)(Q-1)} \times \sum_{x=1}^{P-1}\sum_{y=1}^{Q-1} \sqrt{\frac{\left(\frac{\partial F_k(x,y)}{\partial x}\right)^2 + \left(\frac{\partial F_k(x,y)}{\partial y}\right)^2}{2}},$$
$$k = R, G, B,$$

where $F_k(x,y)$ is the pixel value of the fused image at position (x,y). The average gradient reflects the clarity of the fused image [13]. It can be used to measure the spatial resolution of the fused image, i.e., a larger average gradient means a higher spatial resolution. The overall image fusion performance measure can be described as:

$$O.P = \frac{\sum_k \left| D_k + Std(D_k, Avg_k) \right|}{3}, \qquad k = R, G, B$$

The small amount of overall performance (O.P) means a higher overall fusion quality.

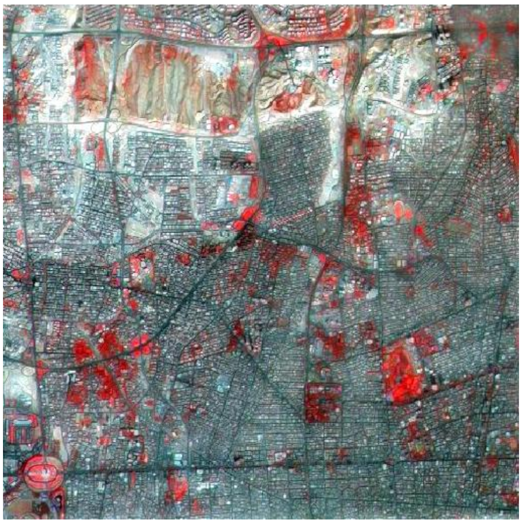
(a)



(b)

(c)

(d)



(e)

Figure 3. Fused images (Dataset 1). IHS (a), Brovy (b), Wavelet-*à trous* (c), Non feedback retina (d), Feedback Retina model (proposed method) (e).

Table 1 shows the spectral discrepancies between the images obtained by different fusion algorithms and the source multispectral image. The average gradients of the images obtained by different fusion algorithms are shown in

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Table 1. Spectral discrepancies between the fused images and the source MS images.

Fusion Methods	Dataset 1 Mean $Avg_{k=R,G,B}$	Dataset 2 Mean $Avg_{k=R,G,B}$	Dataset 3 Mean $Avg_{k=R,G,B}$
IHS	38.76	28.59	31.31
Brovey	40.93	22.47	22.86
DWT	31.72	22.99	21.10
a-trous wavelet	32.10	23.95	21.75
Non feedback-Retina	30.33	22.41	20.52
Proposed method	30.11	20.85	19.94

Table 2. The average gradients of the fused images.

Fusion Methods	Dataset 1 Mean $Avg_{k=R,G,B}$	Dataset 2 Mean $Avg_{k=R,G,B}$	Dataset 3 Mean $Avg_{k=R,G,B}$
IHS	15.69	15.34	13.63
Brovey	13.59	13.02	11.62
DWT	15.79	15.06	13.49
a-trous wavelet	15.37	15.06	13.45
Non feedback-Retina	14.98	14.98	13.40
Proposed method	15.46	13.96	12.90

Table 3. The overall fusion performance measure based on discrepancy and average gradient.

Fusion Methods	Dataset 1 O.P	Dataset 2 O.P	Dataset 3 O.P
IHS	18.35	12.65	14.60
Brovey	20.08	9.71	10.27
DWT	14.32	9.53	8.83
a-trous wavelet	14.64	10.07	9.20
Non feedback-Retina	13.72	9.22	8.51
Proposed method	13.49	8.57	8.30

Table 2. Table 3 represents overall performance of different fusion methods. These results demonstrate that the proposed method preserves more spatial features with less spectral distortion.

V. Conclusion

The goal in image fusion is to reduce uncertainty and minimize redundancy in the output while maximizing relevant information particular to an application. In this research, we proposed a novel method for multimodality medical image fusion. The retina fusion technique is reviewed and analyzed in this study. To reduce the spectral distortion and improve the fusion quality, feedback retina based fusion approach is proposed. The fusion results are compared with conventional fusion methods by visual analysis and statistical analysis. The analysis results demonstrate that the proposed algorithm significantly improves the spectral and spatial quality compared to the non-feedback retina and other conventional models.

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