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An IHS-Based Fusion for Vegetation Enhancement in IKONOS Imagery

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Abstract—
In monitoring vegetation change and urban planning, the measure and the mapping of the green vegetation over the Earth play an important role. The normalized difference vegetation index (NDVI) is the most popular approach to generate vegetation maps for remote sensing imagery. Unfortunately, the NDVI generates low-resolution vegetation maps. High-resolution imagery, such as IKONOS imagery, can be used to overcome this weakness leading to better classification accuracy. Hence, it is important to derive a vegetation index providing the high-resolution data. Various scientific researchers have proposed methods based on high-resolution vegetation indices. These methods use image fusion to generate high-resolution vegetation maps. IKONOS produces high-resolution panchromatic (Pan) images and low-resolution multispectral (MS) images. IKONOS images can be fused or pan-sharpened for the visual interpretation of large-area-scale applications. Generally, for the image fusion purpose, the conventional linear interpolation bicubic scheme is used to resize the low-resolution images. This scheme fails around edges and consequently produces blurred edges. Our project designed a new index that provides high-resolution vegetation maps for IKONOS imagery.

I. INTRODUCTION

EARTH observation satellites provide multispectral (MS) and panchromatic (PAN) data that have different spatial, spectral, temporal, and radiometric resolutions. The fusion of a PAN image that has high spatial but low spectral resolutions with MS images that have low spatial but high spectral resolutions is a key issue in many remote sensing applications that require both high spatial and high spectral resolutions. The fused image may provide feature enhancement and classification accuracy increase. The design of a sensor to provide both resolution requirements is limited by the tradeoff between spectral resolution, spatial resolution, and signal-to-noise ratio of the sensor. The spectral and spatial resolutions have an inverse relationship. Thus, a high spectral resolution results in a low spatial one and vice versa. Hence, there is an increasing use of image processing techniques to fuse the available MS and PAN images.

II. PROBLEM POSITIONING

A. *Spectral Response of IKONOS*

Fig. 3.1 shows the spectral responses of IKONOS. The MS and PAN bands are different. In this spectral response, the following three major problems are noticeable.

1) The PAN band response extends from the visible to the NIR part of the electromagnetic spectrum.
2) Most of the B band response is out of the PAN band range.
3) The G and B bands substantially overlap.

In the context of Spot sensor, the PAN image is obtained only in the visible part of the electromagnetic spectrum. Therefore, I component produced by combining the R, G, and B bands appears like the PAN image. The IHS-based pan-sharpening consists of
1) Using the R, G, and B bands to compute the HIS components
2) Replacing the I component by the PAN image and then reversely transforming the PAN, H, and S components from the IHS space into the RGB space, resulting in a fused color image. If the I component has a high correlation with the PAN image being fused, this will produce a satisfactory fusion result. However, in the context of IKONOS, the PAN image is produced in a larger band: from visible to NIR. Therefore, the I component obtained from combining R, G, and B only often differs from the PAN image. Hence, color distortion becomes a common problem of the IHS technique for IKONOS imagery.

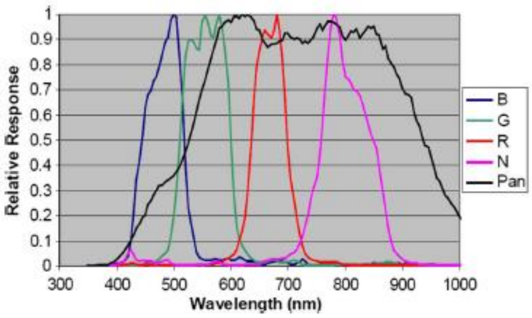

Fig .3.1 ikonos spectral response

Obviously, the color distortion in the fusion process results from these mismatches. Generally speaking, if the spectral responses of the MS bands do not lay perfectly within the PAN band, as it happens with the most advanced very high resolution imagers, namely, IKONOS, then the IHS-based methods may yield poor results in terms of spectral fidelity. Therefore, in order to improve the fused results, the spectral response must be considered in the merging process.

B. IHS Fusion Technique

The IHS transform is widely used as an image fusion technique to exploit the complementary nature of multi-sensor image data. Before conducting an IHS fusion, the color image should be registered with the high-resolution PAN image and should be resampled to the same pixel size with the PAN image. Next, the three bands (R, G, and B) of a color image have to be transformed from the RGB space into the IHS space. Normally, the IHS fusion consists of the following steps.

1) Upsample the RGB images to the PAN pixel size, and then, convert them to the IHS components

$$\begin{bmatrix} I \\ v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

where R, G, and B represent the corresponding values in the original RGB image and v1 and v2 are the intermediate components used to calculate the H and S components.

2) Substitute the intensity component I with the coregistered PAN image.

3) Transform the H, S, and substituted PAN image back to the RGB space by the inverse IHS transform

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \times \begin{bmatrix} PAN \\ v_1 \\ v_2 \end{bmatrix} \quad (2)$$

R', G', and B' are the corresponding values to RGB in the fused images.

By rewriting (2), the authors present a computationally efficient method (FIHS) as

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R+\delta \\ G+\delta \\ B+\delta \end{bmatrix} \quad (3)$$

where δ = PAN-I and I = (R+G+B)/3 (4)

Equation (3) states that the fused image [R',G' ,B']T can be obtained easily and directly from the original image [R,G,B]T by simple addition operations. The fused image obtained after the FIHS fusion provides the full details of PAN but introduces color distortions. In (3), a large value of δ appears to cause a large spectral distortion in the fused images. In order to reduce this effect, one must generate an intensity component I, which must be as close as possible to the PAN image. The authors demonstrated that, when the NIR band is available, a possible solution is to define a GIHS transform by including the response of the NIR band into the intensity component. In this case, I is obtained by weighting each band with a set of coefficients. The choice of these weights can be related to the spectral responses of the PAN and MS bands by considering the spectral characteristics of the sensors. By differently weighting the contributions coming from the MS images, one obtains

$$I = w_R R + w_G G + w_B B + w_{NIR} NIR \cong PAN. \quad (5)$$

Two algorithms, corresponding to two sets of the weighting coefficients (w_R, w_G, w_B, w_{NIR}), are presented in [12]. The first scheme consists of the GIHS method, where the intensity component is simply the average of the four MS images, i.e., I = (R + G + B + NIR)/4. The second algorithm uses the SAIHS method with another weighting for I : I = (R + aG + bB + NIR)/3. The values of 0.75 and 0.25 corresponding to a and b, respectively, are found to be suitable in fusing the IKONOS images. With these considerations, a general expression can be clearly defined for the fusion process as

$$\text{Fused Band} = \text{Band} + \delta, \quad \delta = \text{PAN} - I \qquad (6)$$

where Band represents one of the MS bands and

$$I = I_3 = (\text{R} + \text{G} + \text{B})/3 \qquad \text{for FIHS} \qquad (7)$$

$$I = I_4 = (\text{R} + \text{G} + \text{B} + \text{NIR})/4 \qquad \text{for GIHS} \qquad (8)$$

$$I = I_{SA} = (\text{R} + a\text{G} + b\text{B} + \text{NIR})/3 \qquad \text{for SAIHS.} \qquad (9)$$

while using GIHS, Choi proposed a new IHS approach for image fusion with an adjustment parameter reflecting the spectral characteristics of the sensors. Instead of using the spectral adjustment in the computation of the I component, he used it to calculate each fused band. His proposed method is expressed as follows:

$$\begin{bmatrix} \text{R}' \\ \text{G}' \\ \text{B}' \\ \text{NIR}' \end{bmatrix} = \begin{bmatrix} \text{PAN} - \frac{(\text{PAN} - I_4)}{t} + (\text{R} - I_4) \\ \text{PAN} - \frac{(\text{PAN} - I_4)}{t} + (\text{G} - I_4) \\ \text{PAN} - \frac{(\text{PAN} - I_4)}{t} + (\text{B} - I_4) \\ \text{PAN} - \frac{(\text{PAN} - I_4)}{t} + (\text{NIR} - I_4) \end{bmatrix} \qquad (10)$$

where t is a tradeoff parameter.
To write (10) in a general expression form, let

$$\alpha = \frac{t-1}{t}. \qquad (11)$$

Then

$$\text{Fused Band} = \text{Band} + \alpha\delta_4, \quad \delta_4 = \text{PAN} - I_4. \qquad (12$$

A suitable value of the tradeoff parameter t for IKONOS images was found to be equal to four; hence, α = 3/4. In IKONOS, the vegetation zones of the MS images are much darker because the vegetation appears to have a relatively low reflectance in the RGB bands. To overcome this problem and to obtain a color-enhanced image, three different tradeoff parameters (t_R = 2.5, t_G = 3.5, and t_B = 2.0) are used. Each MS band was enhanced with a parameter reflecting its spectral response.

The technique presented also tries to solve the same problem. Then, a new experimental results, given in (17), is proposed to boost the G band in vegetated areas. The obtained modified FIHS was then derived as

$$\begin{bmatrix} \text{R}' \\ \text{G}' \\ \text{B}' \end{bmatrix} = \begin{bmatrix} \text{R} + \delta_3 \\ \text{G} + \delta_3' \\ \text{B} + \delta_3 \end{bmatrix} \qquad (13)$$

$$\text{with } \delta_3 = \text{PAN} - I_3. \qquad (14)$$

To detect a vegetated area, two ways are proposed, which are the following.

1) If VI is considered, then

$$\delta_3' = \begin{cases} \delta_3 & \text{VI} \le 0 \\ k\delta_3 & \text{VI} > 0. \end{cases} \qquad (15)$$

2) If NDVI is used, then

$$\delta_3' = \begin{cases} \delta_3 & \text{NDVI} \le \theta \\ k\delta_3 & \text{NDVI} > \theta \end{cases} \qquad (16)$$

where k is a constant that is fixed to two for IKONOS imagery.

In practice, the threshold θ is manually selected. The idea of using the vegetation detection in the fusion procedure, reported, is that the fused images have a true natural color, especially in the vegetated zones.

Color Enhancement

In order to show the capabilities of the proposed method, two examples (A and B) are shown in Fig. 7(a). The first case is shown in Fig. 7(b), (d), and (f). This area is chosen in order to demonstrate the improvement for the G and B bands. The proposed method produces the best results, as can be seen: the green and blue colors appear natural. In Fig. 7(c), (e), and (g), corresponding to the second case, the importance of using the new VI (HRNDVI) is highlighted. The fused results shown in Fig. 7(e) and (g) are obtained using the conventional NDVI and the HRNDVI, respectively.

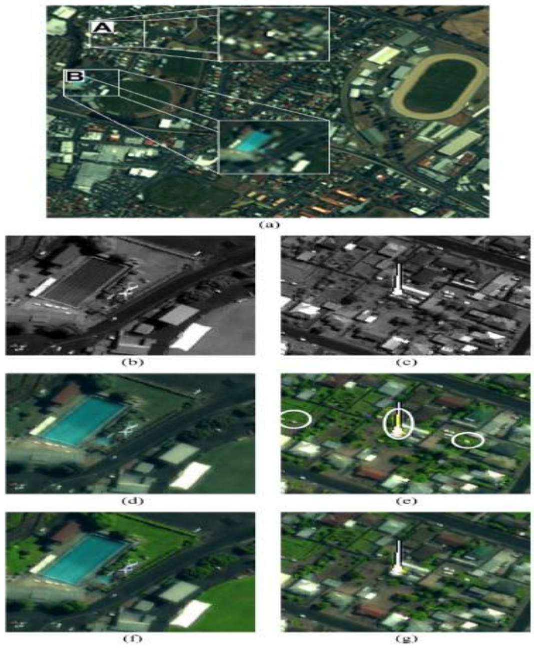

Fig. 7. (a) RGB image with two zoomed areas (A and B). (b) PAN image for area A. (c) PAN image for area B. (d) Proposed method results with β_2 using NDVI. (e) Proposed method results with β_1 using HRNDVI. (f) and (g) Proposed method results with β_2 using HRNDVI.

In the proposed method, enhancement is applied only in the vegetation areas. Therefore, if some errors are made in the vegetation detection process, the final result is affected. As shown in Fig. 2, the NDVI introduces some errors in the "monument" area. Then, enhancing these false vegetation areas introduces color distortions, where a white color pixel appears as yellow due to an increase in the G band and a decrease in the B band. One can notice that using the HRNDVI has eliminated the color distortions (bright regions characterized by a fluorescent color) that are observed (white circles) in Fig. 7(e) when using the conventional NDVI. Our method is based on vegetation detection in order to enhance the vegetated area. Hence, if the detection of the vegetation presents some error, color distortion may be introduced in the resulting image. Using the HRNDVI minimizes this error, especially in regions with sharp edges.

CONCLUSION

A new method has been presented for both image fusion and vegetation visualization. It is based on the GIHS, with some G and B bands enhancement in the vegetated zones. In this context, a modified VI (HRNDVI) has been proposed for a better vegetation detection. This new technique has been evaluated both subjectively and objectively and has been proven to be efficient in the process of pan-sharpening IKONOS images. For that reason, most classical evaluation indexes were used to assess the quality of the resulting images. The experimental results show that the method performs well on the images that contain mixed or mostly vegetated areas. The results were then compared with those obtained from other existing approaches. This comparison clearly shows that the new method gives very good visual results and produces non distorted and perfectly natural image colors. Moreover, in terms of quantitative indexes, this approach provides a global appreciable fusion quality and improves the spectral and spatial correlations in dense vegetation images. In addition to its performance, this method still remains as simple as the other IHS-based techniques.

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