A Comparative Study of Image Fusion

Sreelekshmi A.N*and Dr. K S Anil Kumar**
*Asst. Prof. Sree Ayyappa College, Eramallikkara,Chengannur,Alappuzha,Kerala
**Principal, Sree Ayyappa College, Eramallikkara, Chengannur,Alappuzha, Kerala

Abstract: Image fusion can be used as a tool to increase the spatial resolution. In that case the high resolution panchromatic imagery is fused with low-resolution often multi-spectral image data. The multispectral images are images created from the several narrow spectral bands. Due to inherent limitations on board in carrying the electronics and transferring the large volumes of data on to the ground, there is a requirement for finding out the methods for improving the spatial resolution by using image processing techniques. Data fusion in image processing addresses such requirements. When discussion is about data, it can be Optical, microwave or other sensors data. Data fusion can be further subdivided into multi-sensor fusion and image data fusion. The image fusion deals with the various techniques and algorithms used for combining image data. It contains all spectral (colour information) details but not spatial details. Panchromatic images are single band images generally displayed as shades of gray. It contains all high spatial details (geometric) but not spectral details. Various fusion algorithms have been developed over the years. Image fusion methods can be broadly classified into two categories - spatial domain and transform domain methods. All these methods improve spatial or spectral resolutions. Hence, there is a requirement for development of newer techniques to fuse high resolution Cartosatseries data with high resolution of spatial and spectral details of all image data type. The result of image fusion is a new image that retains the most desirable information and characteristics of each input image. The main application of image fusion is merging the gray-level high-resolution panchromatic [PAN] image and the colored low-resolution multispectral [MS] image.

Keywords: Image fusion, pan chromatic image, spatial resolution, spectral resolution, HIS, PAN, Multi spectral image, Spatial domain, Spectral domain.

Introduction

Nowadays in remote sensing applications, the increasing availability of space sensors gives a motivation for different image fusion algorithms. Several situations in image processing require high spatial and spectral resolutions in a single image. But most of the available equipment is not capable of providing such information, either by design or because of observational constraints. The aim of the data fusion method is to combine two images that have been acquired at a different spatial resolution to produce an image with the spatial information of the high resolution image and the spectral information of the low spatial resolution image. There are mainly two types of data fusion process. They are multi sensor fusion and image data fusion. One of the component based method is the IHS. Thus image fusion techniques allow the integration of different information sources.

Inormal IHS Transformation

The colour monitors used for image display on image processing systems have three colour guns. These correspond to red, green, and blue (R, G, B), the additive primary colours. When displaying three bands of a multiband data set, the viewed image is said to be in RGB space. However, it is possible to define an alternate colour space that uses intensity, hue (H), and saturation (S) as the three positioned parameters (in line of R,G, and B). Intensity is the overall brightness of the scene and varies from 0 (black) to 1 (white). Saturation represents the purity of colour and also varies linearly from 0 to 1. Hue is representative of the colour or dominant wave length of the pixel. It varies from 0 at the red midpoint through green and blue back to the red midpoint at 360. It is a circular dimension and must vary from 0 to 360 to define the entire sphere.
The standard merging methods of image fusion are based on Red-Green-Blue (RGB) to Intensity-Hue-Saturation (IHS) transformation. The usual steps involved in satellite image fusion are as follows [3]:

1. Register the low resolution multispectral images to the same size as the panchromatic image.
2. Transform the R, G and B bands of the multispectral image into IHS components.
3. Modify the panchromatic image with respect to the multispectral image. This is usually performed by Histogram matching of the panchromatic image with Intensity component of the multispectral images as reference.
4. Replace the intensity component by the panchromatic image and perform inverse transformation to obtain a high resolution multispectral image.

RGB to HIS

This enables to apply an algorithm which transforms red, green, and blue values to intensity, hue and saturation (IHS) values..The algorithm for RGB to IHS transformation :-

$$R=(M-r) / (M-m) \quad \text{Eqn.(1)}$$
$$G=(M-g) (M-m) \quad \text{Eqn.(2)}$$
$$B=(M-b) (M-m)$$

where:

R, G, B is each in the range of 0 to 1.0. r, g, b is each in the range of 0 to 1.0. M is largest value among r, g and b. m is least value among r, g, or b. At least one of the R, G, or B values is 0, corresponding to the colour with the largest value, and at least one of the R, G, or B values is 1, corresponding to the colour with the least value.

The equation for calculating the intensity value in the range of 0 to 1.0 is:

$$I= (M+m) / 2 \quad \text{Eqn. (3)}$$

The equations for calculating saturation in the range of 0 to 1.0 are:

If M = m, S = 0 , If I <= 0.5, S = (M-m) / (M+m) ,If I > 0.5, S = (M-m) / (2-M-m)

The equations for calculating hue in the range of 0 to 360 are:

If M = m, H = 0

If R = M, H = 60 * (2 + b - g) ,If G = M, H = 60 * (4 + r - b) , If B = M, H = 60 * (6 + g - r)

Where:

R, G, B is each in the range of 0 to 1.0.

M = largest value, R, G, or B ,m = least value, R, G, or B

An Efficient Saturation Compensated HIS Method

As explained by Te-Ming *et.al*, saturation compensation can be accomplished by simply shifting So to S' or by multiplying with (1 +ΔS/S_0). That is:

$$\begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix} = \begin{bmatrix} Pan \\ Pan + \\ Pan \end{bmatrix} \begin{bmatrix} 1 + \frac{\Delta S}{So} \end{bmatrix} \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & -1/\sqrt{2} \\ \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} V1_0 \\ V2_0 \end{bmatrix} \quad \text{Eqn. (4)}$$

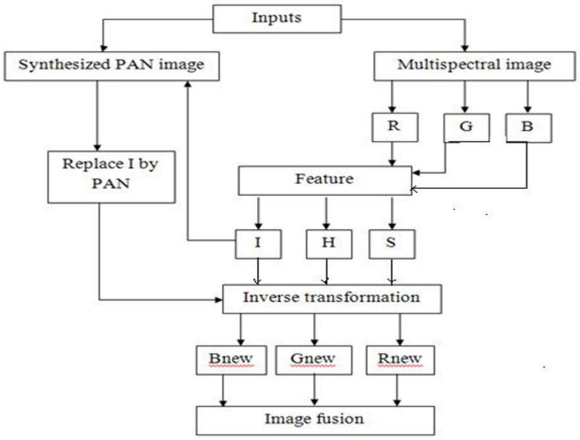
It is made computationally efficient by:

$$\begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2}\ Pan \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} \Upsilon'.\ 1_0 \\ \Upsilon'.v2_0 \end{bmatrix}$$
$$= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2}\ \Upsilon'.1 \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} + \begin{bmatrix} (Pan- \Upsilon'.1) \\ \Upsilon'.v1_0 \\ \Upsilon'.v2_0 \end{bmatrix}$$
$$= \Upsilon^{1}. \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} \Upsilon'' \\ \Upsilon'' \\ \Upsilon'' \end{bmatrix} \quad \text{Eqn. (5)}$$

Where Υ' = 1/Pan =1+ΔS/S0 and Υ'' = Pan-Υ'. 1

Overview of the Proposed Method

The proposed method is the new panchromatic image is fused with multispectral image. The new panchromatic image is created by using apply the multiple linear regression. Then we get the synthetic panchromatic image. The advantage of the panchromatic image is more spatially detailed one. Here we are applying the saturated compensated HIS image fusion method for applying image fusion [1]. So fused with new panchromatic image and multispectral image finally we get the highly spatially and high spectrally detailed image as the output.



The proposed method is related to the multiple linear regression based one. The multispectral image is fused with panchromatic image then we get one image with especially high resolution and also spectrally high resolution image. The main differences of the other HIS methods with this are here not take directly as the panchromatic image.The multiple linear regression equation is

$$Y = B*X \qquad \text{Eqn. (6)}$$

Where, "B" is the matrix of B1, B2 and B3. This is considered as the coefficient matrix of regression.
"Y" is the panchromatic image matrix and "X" is the multispectral image matrix.

To find the synthesized panchromatic image

PAN image is 1xN matrix and that is equated to the three 3xN matrix of multispectral image and regression coefficients like a, b and c (1x3 matrix). Here we get the values of a, b and c. This coefficient matrix is multiplied with multispectral image matrix finally we got one new image matrix, called synthesized PAN image.In this method calculate to find the coefficient matrix of regression from this equation[4]:

B = (inverse (transpose (X)) * (X)) * (transpose (X)) * (Y) Eqn (7)

From here we get one matrix that is multiplied with multispectral image finally we get one binary image, called synthesized panchromatic image. In the proposed method we use this synthesized panchromatic image is fused with multispectral image. Here the saturation compensated image fusion is applied for the image fusion.The proposed method we will calculate the regression coefficients and that value is equating to the original PAN image. Then we get the coefficients, that value is multiplied by the multispectral image finally we will get one new image called synthesized PAN image. This new PAN image is used to image fusion.

Proposed Method

According to Chen et al., 2003 in the IHS transformation image fusion, the Intensity (I), the spatial component and the Hue (H) and the Saturation (S), the spectral components of an image are generated from the RGB image. The Intensity (I) component is then substituted by the high resolution panchromatic image to render a new image in RGB, which is referred as the fused image. This is also called as a sharpened image. In the IHS transformation the three bands of the lower resolution image is utilized to translate it into the IHS space. Then, a contrast stretch is applied to the high resolution image, so that the stretched image has the same variance and average as the intensity component image. The stretched image that is the higher resolution image substitutes the intensity component before the image is metamorphosed to original colorimage.As explained by Te-Ming et.al, saturation compensation can be accomplished by simply shifting so to S" or by multiplying with $(1+\Delta S/S_0)$ That is:

$$\begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix} = \begin{bmatrix} Pan \\ Pan \\ Pan \end{bmatrix} + \left[\left(1 + \frac{\Delta S}{So}\right)\right] \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} & V1_0 \\ -1/\sqrt{2} & -1/\sqrt{2} & V2_0 \\ \sqrt{2} & 0 & \end{bmatrix} \qquad \text{Eqn. (8)}$$

It is made computationally efficient by [7]

$$\begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} Pan \\ Y', v1_0 \\ Y', v2_0 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 \quad \sqrt{2} & 0 & \end{bmatrix} \begin{bmatrix} \Upsilon' ,1+(Pan- \Upsilon' ,1) \\ \Upsilon' , v1_0 \\ \Upsilon' , v2_0 \end{bmatrix}$$

$$= \Upsilon' \cdot \begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix} + \begin{bmatrix} \Upsilon'' \\ \Upsilon'' \\ \Upsilon'' \end{bmatrix}$$

Eqn. (9)

Where

$\Upsilon' = 1/Pan = 1 + S/S_0$ and $\Upsilon'' = Pan – \Upsilon' , 1$

Experimental Results

The following data presents thumbnails of the output images and also compares them using the parameters like mean, median, standard deviation and universal image quality index (Q-factor).The methods are implemented on normal images.

From the above data, it can be found out that SATURATED COMPENSATED HIS method outperforms the NORMAL IHS method. The HIS method performs better than YIQ, and in particular, because the spectral distortion in the fused bands is usually less noticeable, even if it cannot be completely avoided. The wavelet based method can further reduce the spectral distortion, and thus the SATURATED COMPENSATED HIS fusion method is the best choice in most cases. Thus spatial domain fusions like IHS, HSV and YIQ may produce spectral degradation. This is particularly crucial in optical remote sensing if the images to fuse were not acquired at the same time. Therefore, compared with the ideal output of the fusion, these methods often produce poor result.

Qualitative analysis

Qualitative analysis involves visual comparison of colour between original Multi Spectral and fused images, and the spatial detail between original Panchromatic and fused images. This method depends on the observers experiences or bias thus some uncertainty is involved [2]

Quantitative analysis

Quantitative approaches involve a set of predefined quality indicators for measuring the spectral and spatial similarities between the fused image and the original Multi Spectral and/or Panchromatic .Amongst all developed objective quality metrics, Entropy, DIV, UQI and C.C are some of the most widely applied metric [2].

IMAGE QUALITY ASSESSMENT

Table:1 Universal Quality index

METHOD	Q-factor
Normal HIS method	0.401
Saturated compensated HIS	0.590

Table : 2Image Quality Analysis

TECHNIQUES	SSIM VALUES		
	BAND 1	BAND 2	BAND 3
Normal IHS	0.0240	0.1136	-0.0216
Saturation compensation IHS	0.0239	0.1116	-0.0219

Universal Image Quality Index [Q-factor]

Universal Image quality index is a new type of quality index proven to be better than widely used distortion metric mean squared error. Instead of using traditional error summation methods, this index is designed by modelling the image distortion as a combination of three factors: loss of correlation, luminance distortion, and contrast distortion [8] . Its definition is given below:-

Let x = {x_i|i =1, 2, …, N} and y = {yi|i = 1, 2, …, N} be the original and the test image signals, respectively, quality indeed is defined as

$$Q = \frac{4\sigma_{xy}xy}{(\sigma x^2 + \sigma y^2)\,[(\overline{x}^2) + (\overline{y})^2]}$$

$$\text{Where} x = \frac{1}{N}\sum_{i=1}^{N} xi, \quad y = \frac{1}{N}\sum_{i=1}^{N} yi$$

$$\sigma_X^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})^2 , \quad \sigma_y^2 = \frac{1}{N-1}\sum_{i=1}^{n}(y_i - y)^2$$

$$\sigma_{xy} = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})(y_i - y)$$

Eqn. (10)

The dynamic range of Q is [-1, 1]. The best value 1 is obtained only if X=Y and the lowest value -1 occurs when y_i= 2x - x_i for all i=0, 1, 2… N.or i=0,1,2,....,n. and also here represents X or x = $\overline{x}$ or $\overline{X}$ and Y or y =$\overline{y}$ or $\overline{Y}$

SSIM

Structural Similarity is based on the idea that the human visual system is highly adapted to process structural information and the algorithm attempts to measure the change in this information between and reference and distorted image. Based on numerous tests, SSIM does a much better job at quantifying subjective image quality than MSE or PSNR.

Entropy

Entropy is a measure of information content of an image and is usually applied in image processing methods as a mean for measuring the information and complexity of images.The Entropy of an image can be calculated by :

Entropy = - $\sum P_i .\log_2 P_i$

P_i = sum(image==i) /N Eqn. (11)

Where P is the estimated probability density function (normalized pixel intensity histogram) of the selected image region.For evaluating the quality of image fusion, the change in Entropy index is applied as quality metric.

R_E = Entropy $_{\text{Fuse dim age}}$ – Entropy $_{\text{Initialim age}}$ Eqn. (12)

It is obvious that when no change occurs in information content of images or both input images (initial and fused image) are the same, the Entropy index RE is equal to 0.

Difference in Variance

DIV inspects fusion quality over the whole image which means difference in variances relative to the original one:s

$$DIV = \frac{\sigma^2 MS - \sigma^2 FMS}{\sigma^2 MS}$$

Eqn. (13)

Where σ^2MS is the variance of the original image and σ^2FMS is the variance of the fused image. This index presents the decrease or increase of information content during fusion process and would be positive for decreasing and negative for increasing change of information.

Correlation Coefficient

Correlation coefficient quantifies the closeness between two images. The correlation coefficient is computed using the following equation:

$$CC = \frac{\sum_1^N \sum_1^M (x - \bar{x})(y - \bar{y})}{\sqrt{\sum_1^N \sum_1^M (x - \bar{x})^2 \sum_1^N \sum_1^M (y - \bar{y})^2}}$$

Eqn. (14)

The correlation coefficient value ranges from -1 to 1, where the value +1 indicates that two images are highly correlated and are very close to each other. The value -1 indicates that the images are exactly opposite to each other.

Experimental Results of Proposed Method

The following data presents thumbnails of the output images and also compares them using the parameters like Mean, Median, Standard deviation, Correlation coefficient, Difference in variance, Entropy and Universal image quality index (Q-factor).

Table 3: Basic qualitative analysis

TECHNIQUES	PROPOSED METHODS		
BASIC STATUS	B1	B2	B3
MIN	2	19	0
MAX	255	255	255
MEAN	95.65	103.19	92.55
STANDARDDEVIATION	71.30	65.66	64.40

Table 4: Universal quality index

PROPOSEDMETHOD	BAND 1 =0.9463	BAND 2 = 0.7601	BAND 3 =0.8618

Table 5

PROPOSED METHOD	DIFFERENCE IN VARIANCE =3.6222 , ENTROPY = 0.0002
PROPOSED METHOD	CORRELATION COEFFICIENT = 0.8902 , SSIM = 0.699

Fusion examples of normal images

Fig 4: Multispectral Image

Fig 5: Panchromatic Image

Fig 6: Proposed His Method

The new proposed method will produce the best result compare than the other existing methods with satellite images and as well as normal images.

Conclusion

In this thesis, the various optical data image fusion methods are studied. The implementation methods of all the mentioned existing and one new fusion methods have been presented which are implemented. The fusion methods implemented are Normal Intensity-Hue-Saturation (IHS) fusion, Saturated compensated HIS and also a proposed method. The output results of the each method are presented [5].

It can be concluded from experimental results that the selection of a particular fusion methods depends on the application at hand. In case of fusing for urban areas spatial resolution is of importance and for agricultural fields spectral is more important than spatial. Hence a method which can preserve both of these equally is desirable. From the implemented Saturated compensated HIS methods are good at preserving spatial quality, Where as Normal HIS is good at preserving the spectral quality. From the statistics it is observed that for the given sample images, saturation compensated IHS scheme outperforms the Normal HIS scheme while Saturated compensated HIS scheme has the best performance with respect to spatial preservation. The proposed method is applicable for normal images as high in spectral and special quality. For the comparison finally conclude that the proposed method is the best one other than existing methods.

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Authors

Sreelekshmi A.N received B. Tech in Information Technology & M. Tech in Computer Vision and Image processing from Amrita VishwaVidyapeetham. Sreelekshmi has been working as Assistant professor (Adhoc) in Department of Computer Science,SreeAyyappa College, Eramallikkara from 2015.

Dr. K S Anil Kumar received MTech in Technology Management (Specialization in IT),Ph.D. in Technology Management (Information Security). Dr. K S Anil Kumar has been working in Department of Computer Science SreeAyyappa College, Eramallikkara from 1995.