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# The IHS-FTR Transformations Based Image Fusion Algorithm For Remote Sensing Images

**Meenu Manchanda[1*], Deepak Gambhir[2]**

[1]Dept. of ECE, Vaish College of Engineering, Rohtak, Haryana, India
[2]Dept. of ECE, Amity School of Engineering and Technology, Bijwasan, New Delhi, India

[*]*Corresponding Author:* meenumanchanda73@gmail.com

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***Abstract***—Image fusion has been attracting researchers with the aim of finding solutions to a wide area of applications. In the area of remote sensing, the increasing availability of imaging sensors, operating in a variety of spectral bands, definitely provides strong motivations. Because of the trade-off observed between sensors with a high spatial resolution with only a few spectral bands and sensors with low spatial resolution having many spectral bands, spatial enhancement of poor-resolution image and vice-versa is desirable. Thus, a new method of fusing different resolution images based on IHS transform and fuzzy transform (FTR) is proposed. The main aim is to produce a fused image with high spatial as well as high spectral resolution by fusing two images, an Ms image and a Pan image, the former with high spectral resolution but poor spatial resolution and the latter with high spatial resolution but poor spectral resolution. Experimental results obtained from the fusion of different pairs of input images prove the effectiveness of the proposed algorithm.

***Keywords—***Remote Sensing, fuzzy transform, image fusion

## I. INTRODUCTION

The field of remote sensing is a continuously growing market with applications like mapping coastal features, discovering and monitoring the rugged topography of the ocean floor, tracking earthquakes and hurricanes etc. These wide ranges of applications are due to the availability of high quality images of most dangerous or inaccessible areas using sensors onboard airborne or spaceborne platforms [1]. However, the information content of a single image is limited by the spatial and spectral resolution of the imaging system. As far as same area is concerned, it is difficult to obtain an image of high spatial resolution as well as high spectral resolution at the same time. For example the Ms image, captured by three sensors operating at green, red and blue spectral wavelengths, contains rich spectral information (i.e. color information) but poor spatial resolution. Whereas, the Pan image, contains no color information but contains rich spatial resolution. Thus, due to tradeoff between spatial and spectral resolutions, spatial enhancement (through Pan image) of Ms image, or equivalently, spectral enhancement (through Ms image) of Pan image is desirable. To meet out these requirements, image fusion techniques that not only allow fusion of images captured using different sensors but also take the advantage of merging complementary spatial and spectral resolution characteristics of different images have been developed in literature. These techniques fuse the Ms image with the Pan image to enhance the spatial resolution of the former, or equivalently, the spectral resolution of the latter.

IHS, PCA and Brovey transform are the most popularly used algorithms in remote sensing. However, these algorithms often result in color distortion. Authors have also proposed high-pass filtering algorithm for fusion of MS and Pan images. The main objective is to extract the spatial details from Pan image and fuse them into Ms image. Multiresolution analysis [2] approaches based on discrete wavelet transform (DWT) and Laplacian transform (LT) have also been used for extraction of spatial details from Pan image. However, MRA algorithms may produce ringing effect thereby degrading the visual quality of the fused image. Recently, fuzzy transform that possess various important properties such as capability of preserving edge information, shift-invariance, better function approximation and smoothing abilities have attracted researchers towards fuzzy transform based image fusion algorithms.

The rest of the paper is structured as follows: an introduction of fuzzy transform is given in Section 2, IHS based fusion algorithm is explained in Section 3, the proposed IHS-FTR based fusion algorithm is presented in Section 4, results of proposed fusion algorithm are illustrated and discussed in Section 5 and finally, conclusion is drawn in Section 6.

## II. Fuzzy Transform

Fuzzy transform (FTR) [3] is an operator that transforms an original space of a continuous or a discrete function into a finite (say N) dimensional vector space. The inverse-FTR transforms back the N-dimensional vector space into original space producing an approximation of the original function. Fuzzy transform possesses various important properties such as better approximation properties, shift invariance, ability of preserving edges, smoothening and noise removing capabilities and therefore has been successfully applied to image compression and decompression, image fusion, solving differential equations, time series analysis etc.

**Definition of fuzzy transform in 2-dimensions**

Let $f(x,y)$ be a 2-dimensional function determined at finite number of nodes $p_1, p_2,\dots,p_N$ in an interval $[\alpha, \beta]$ and $q_1, q_2, \dots, q_M$ in an interval $[\gamma, \delta]$ that are sufficiently dense with respect to the fuzzy partitions $A_1, A_2, \dots, A_N$ and $B_1, B_2, \dots, B_M$ i.e. for each $i=1, 2, \dots, N$ there exists $u=1, 2, \dots, n$ and $A_u(p_i)>0$ and also for each $j=1, 2, \dots, M$ there exists $v=1, 2, \dots, m$ and $B_v(q_j)>0$.

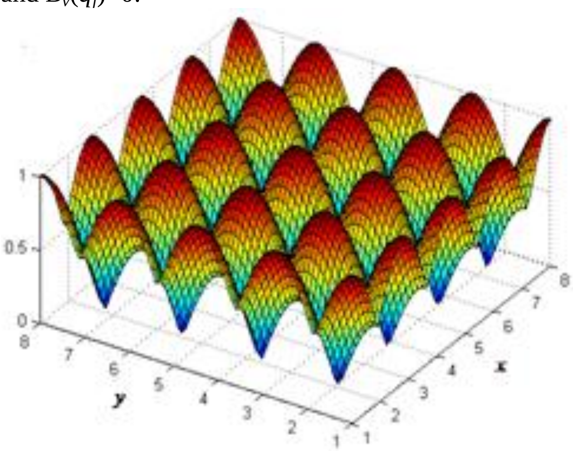



Fig. 1. A 2-dimensional uniform fuzzy partition in an interval [1, 8] × [1, 8]

A 2-dimensional uniform fuzzy partition in an interval $[\alpha, \beta] = [1, 8]$ and $[\gamma, \delta] = [1, 8]$ is shown in Fig. 1. For more details on FTR, interested readers may refer to [4]. The FTR of $f(x,y)$ is:

$$F_{nm} = \begin{bmatrix} F_{11} & F_{12} & \cdots\cdots & F_{1m} \\ F_{21} & F_{22} & \cdots\cdots & F_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ F_{n1} & F_{n2} & \cdots\cdots & F_{nm} \end{bmatrix}$$

Where $F_{uv}$ are the coefficients of fuzzy transform, defined as:

$$F_{uv} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} f(p_i,q_j)A_u(p_i)B_v(q_j)}{\sum_{i=1}^{N}\sum_{j=1}^{M} A_u(p_i)B_v(q_j)} \qquad (1)$$

These coefficients represent the weighted average of the original function and the weights are described by the membership functions. Each coefficient $F_{uv}$ possesses local information about the original function.

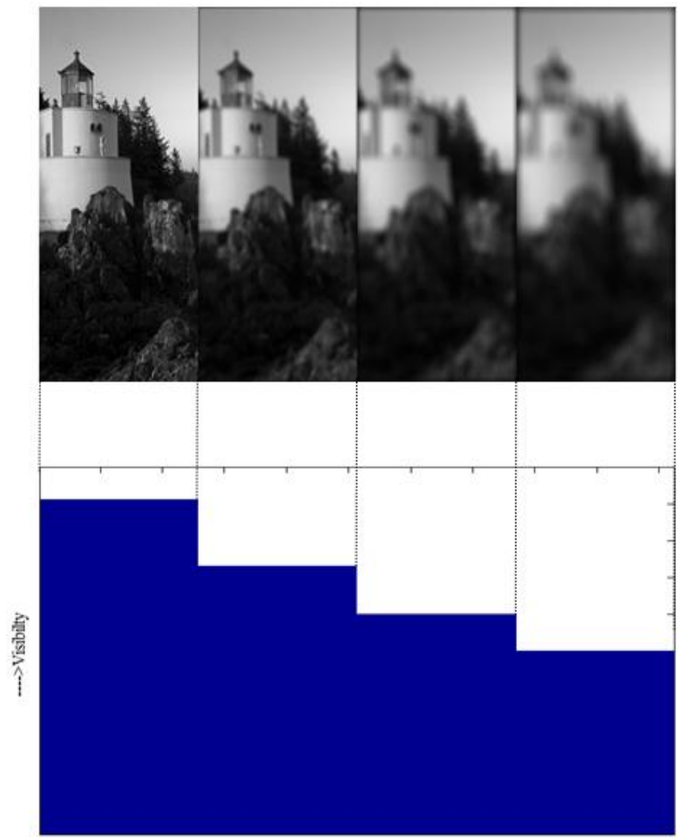



Fig. 2. Significance of visibility in image processing

The inverse fuzzy transform (inv-fuzzy transform) is defined as:

$$\hat{f}(p_i,q_j) = \sum_{u=1}^{n}\sum_{v=1}^{m} F_{uv}A_u(p_i)B_v(q_j) \qquad (2)$$

## III. Standard IHS Transform

The IHS transform is considered to be very useful for developing image processing algorithms based on color descriptions that are natural and intuitive to humans. The IHS transformation [5]

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

$$H = \tan^{-1}\frac{v2}{v1} \text{ and } S = \sqrt{v1^2 + v2^2} \quad (4)$$

separates the spectral and spatial information contained in a RGB color image. The spectral information is represented using H and S component while the spatial information is represented using I-component.

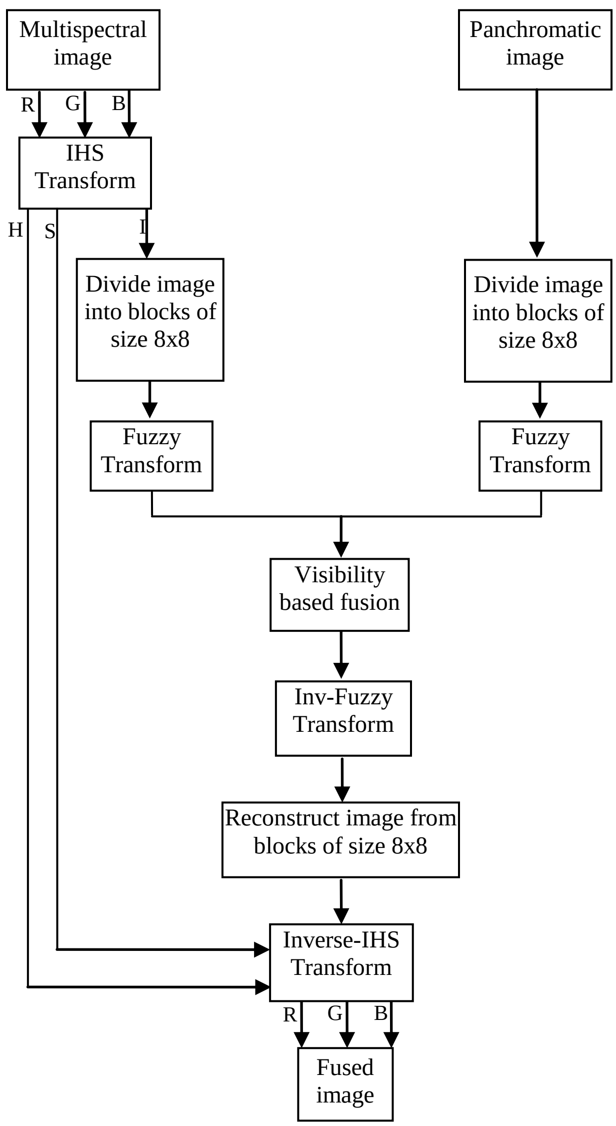



Fig. 3 The proposed algorithm

The image is then enhanced by performing some mathematical operation on the I-component thereby altering its spatial information.

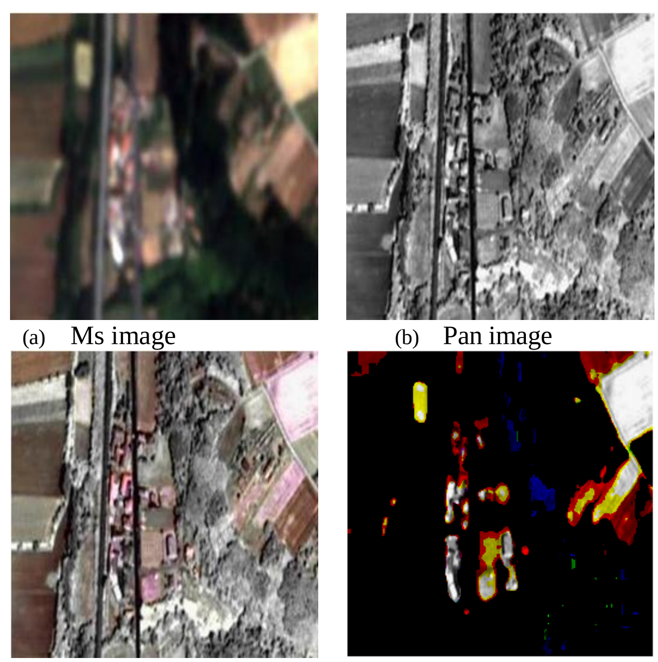
Generally, the appearance of the higher resolution panchromatic image closely resembles the intensity component of IHS representation of an image and therefore during fusion the I-component is replaced by the Pan image. Then reversing the IHS transformation results in a high quality fused image.

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

(5)

**Steps:**

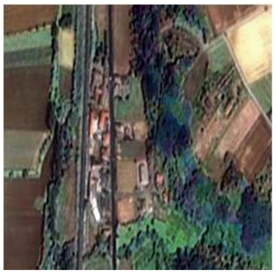
1. The low resolution Ms image after being spatially aligned and re-sampled to the same resolution as the Pan image is transformed into I, H and S components (Equation 3 and Equation 4).
2. The spectral difference between the two images (Ms and PAN) which may be due to different acquisition time or different sensors can be compensated by replacing the spatial component (I) of Ms image by Pan image.



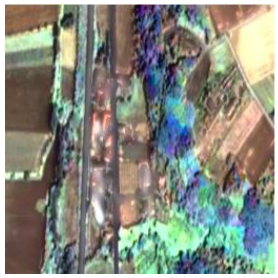
(a) Ms image (b) Pan image

(c) IHS (d) Brovey



(e) NSCT



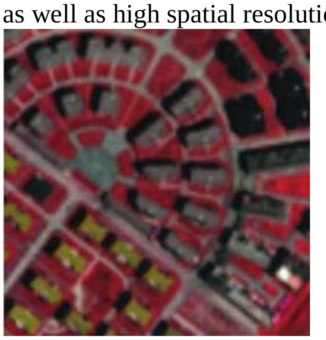
(f) Proposed

Fig. 4 Original images (Pair 1) and Fused images

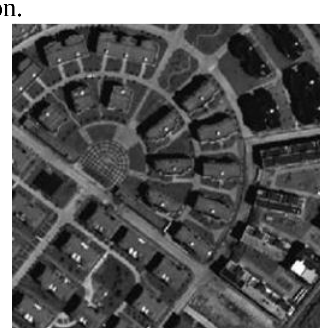
3. The fused RGB color image is then obtained by performing the inverse IHS transformation (Equation 5). The main advantage of this method of fusion is that it requires very little time for computation. However, it adversely affects the spectral information of the original Ms image and also suffers from three band limitation. This method is highly suitable for visual analysis but not for machine classification based on the spectral signatures of the original image.

## IV. Proposed Algorithm

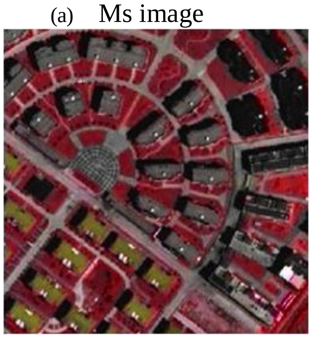
The main aim of the proposed algorithm is to fuse the Ms and Pan images, thereby combining the spectral information contained in Ms image and the spatial features present in Pan image. The proposed algorithm incorporates the property of human visual system i.e. visibility in the fusion process to produce a fused image with high spectral as well as high spatial resolution.



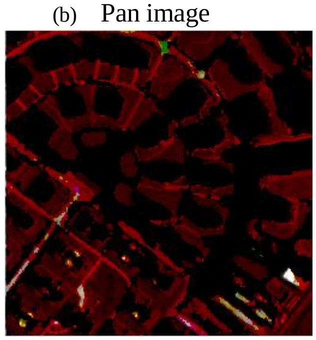
(a) Ms image



(b) Pan image



(c) IHS



(d) Brovey

(e) NSCT

(f) Proposed

Fig. 5 Original images (Pair 2) and Fused images

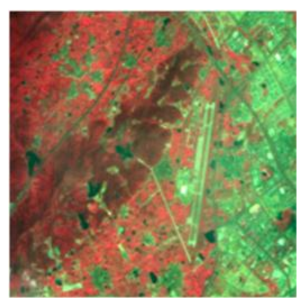
Visibility of an image [6] is defined as:

$$V(X)=\frac{1}{G\times H}\sum_{i=1}^{G}\sum_{j=1}^{H}\frac{1}{X_{mean}^{c}}\frac{|X(i,j)-X_{mean}|}{X_{mean}} \quad (6)$$

where $G\times H$ represents the size of image *X*, *c* is a visual constant with value between 0.6 to 0.7 and $X_{mean}$ is the mean grey value of the image *X*. Fig 2 shows the significance of visibility in image processing. From this figure, it is observed that the value of visibility decreases with the amount of spatial details present in an image.

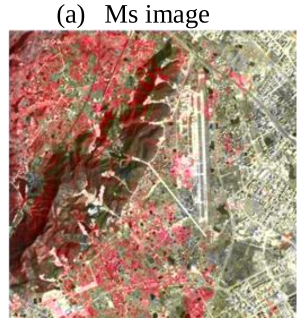
The proposed fusion algorithm is diagrammatically represented in Fig. 3 and is summarized below:

1. The input Ms image is co-registered to the same area as input Pan image in order to have the same size.
2. The R, G and B bands of Ms image are transformed into IHS components (Equation 3 and Equation 4).
3. The I-component of Ms image (I_Ms) and the Pan image are divided into blocks of size $8\times 8$. These blocks are fuzzy transformed and fused using visibility based fusion rule. Mathematically,

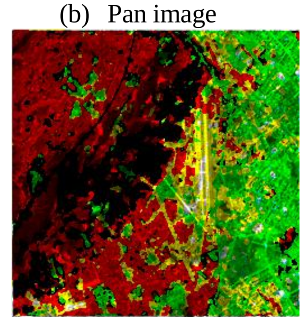


(a) Ms image

(b) Pan image

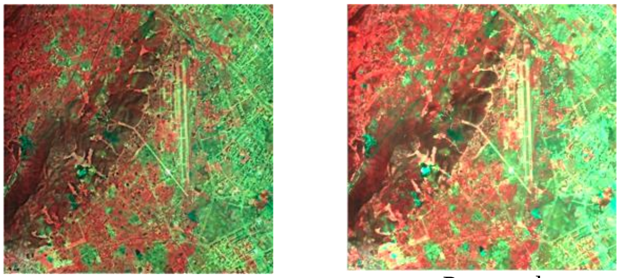


(a) IHS



(b) Brovey



(c) NSCT (d) Proposed

Fig. 6 Original images (Pair 3) and Fused images

If $V(\, w_{g\times h}(FTR_{I\_MS}(u,v))) > V(\, w_{g\times h}(FTR_{Pan}(u,v)))$

then $FTR_{I\_Fused}(u,v) = FTR_{I\_MS}(u,v)$

elseif $V(\, w_{g\times h}(FTR_{I\_MS}(u,v))) < V(\, w_{g\times h}(FTR_{Pan}(u,v)))$

then $FTR_{I\_Fused}(u,v) = FTR_{Pan}(u,v)$

else $V(\, w_{g\times h}(FTR_{I\_MS}(u,v))) = V(\, w_{g\times h}(FTR_{Pan}(u,v)))$

then $FTR_{I\_Fused}(u,v) = 0.5(FTR_{I\_MS}(u,v) + FTR_{Pan}(u,v))$

Where $V(\, w_{g\times h}(FTR_{I\_MS}(u,v)))$ and $V(\, w_{g\times h}(FTR_{Pan}(u,v)))$ are the visibility (using Equation 6) of $(u,v)^{th}$ FTR coefficient of Ms and Pan images respectively, in a neighbourhood of size $g\times h$ centered over it.

4. Finally, inv-fuzzy transform is applied to achieve the fused I-component.
5. The I-component of Ms image is then replaced by the fused I-component.
6. Final new merged RGB Ms image is obtained by performing reverse IHS to RGB transform.

Table 1. Comparison of SD, En and CC of original Ms and various fused images for Pair 1

| Images | Bands | SD | En | CC |
|---|---|---|---|---|
| Original Ms | r | 58.4777 | 7.4384 | - |
| | g | 48.9571 | 7.2759 | - |
| | b | 41.0268 | 7.0286 | - |
| IHS fused image | r | 55.0834 | 7.5156 | 0.3343 |
| | g | 55.4742 | 7.5718 | 0.2823 |
| | b | **56.5184** | 7.4731 | 0.2211 |
| Brovey fused image | r | 55.9735 | 1.8461 | 0.7863 |
| | g | 57.8611 | 1.1488 | **0.7448** |
| | b | 51.3894 | 0.9912 | 0.6402 |
| NSCT fused image | r | 50.9252 | 7.5166 | 0.8405 |
| | g | 45.3841 | 7.4107 | 0.7172 |
| | b | 36.1427 | 7.1125 | 0.6334 |
| Proposed fused image | r | **59.3315** | **7.5191** | **0.8534** |
| | g | **59.6961** | **7.5751** | 0.3238 |
| | b | 48.4556 | **7.5497** | **0.6454** |

## V. EXPERIMENTAL RESULTS AND DISCUSSION

In order to validate the performance of the proposed algorithm, fusion experiments have been conducted on various pairs of Ms and Pan images (named as Pair 1, Pair 2 and Pair 3). In addition, the obtained fusion results have been visually compared with the results of IHS, Brovey and NSCT based fusion methods in Fig. 4 – Fig. 6.

From these figures it is observed that both the spectral resolution as well as the spatial resolution have been enhanced in the fused images obtained from the proposed algorithm, in comparison to the original images. It is also observed that the sharpness of the fused images obtained from the proposed algorithm has also been significantly improved. In addition to the visual comparison, objective comparison using the popularly used indexes [7,8]: standard deviation (SD), entropy (En) and correlation coefficient (CC) have also been performed to prove the performance of the proposed algorithm.

SD, an important index, is used to determine the details present in an image by measuring the deviation of values with respect to the mean of the image. En measures the information of the fused image obtained through various fusion algorithms. High value of En indicates higher amount of information contained in an image. CC reflects the correlation extent between two images. CC can assume values in the range of -1 to +1. When the images are similar, CC is close to 1 and when two images are exactly similar then CC is +1.

Table 2. Comparison of SD, En and CC of original Ms and various fused images for Pair 2

| Images | Band | SD | En | CC |
|---|---|---|---|---|
| Original Ms | r | 39.5439 | 7.1092 | - |
| | g | 32.8046 | 6.7425 | - |
| | b | 29.4338 | 6.6832 | - |
| IHS fused image | r | 44.3268 | 7.3284 | 0.8208 |
| | g | 38.8085 | **7.0795** | 0.7591 |
| | b | 36.7984 | 7.0663 | 0.7217 |
| Brovey fused image | r | 45.4325 | 4.1777 | 0.6167 |
| | g | 17.6301 | 0.2447 | 0.3734 |
| | b | 14.4351 | 0.1714 | 0.3595 |
| NSCT fused image | r | 37.6016 | 7.1257 | 0.8652 |
| | g | 33.9218 | 6.7743 | 0.9305 |
| | b | 31.1332 | 6.7401 | 0.9118 |
| Proposed fused image | r | **46.8065** | **7.3758** | **0.8896** |
| | g | **39.1295** | 6.9501 | **0.9315** |
| | b | **37.0401** | **7.1009** | **0.9128** |

The values of SD and En for each band of original Ms image as well as for each band of fused images obtained using different fusion methods have been shown in Table 1 – Table 3 for Pair1, Pair2 and Pair 3 images respectively. CC between each pair of fused and original Ms bands have also been reported in these tables. From these tables, it is observed that the objective results are in agreement with the visual results indicating that the proposed method is successful in fusing the high spatial details contained in Pan image and high spectral information contained in Ms image into a single fused image. The fused image, so obtained, has better visual effect.

Table 3. Comparison of SD, En and CC of original Ms and various fused images for Pair 3

| Images | Band | SD | En | CC |
|---|---|---|---|---|
| Original Ms | r | 40.3434 | 7.3485 | - |
| | g | 50.7627 | 7.6039 | - |
| | b | 25.6234 | 6.6571 | - |
| IHS fused image | r | 50.1393 | 7.4952 | 0.3286 |
| | g | 56.8773 | 7.8009 | 0.5456 |
| | b | 24.4185 | 7.7372 | 0.4856 |
| Brovey fused image | r | 64.4012 | 5.2555 | 0.6863 |
| | g | 72.1324 | 4.1306 | 0.7996 |
| | b | 28.2673 | 0.3850 | 0.4664 |
| NSCT fused image | r | 42.2197 | 7.3485 | 0.7367 |
| | g | 53.9723 | 7.6039 | **0.8621** |
| | b | 28.6543 | 6.6571 | 0.7969 |
| Proposed fused image | r | **65.7841** | **7.3533** | **0.7454** |
| | g | **73.4019** | **7.8206** | 0.8237 |
| | b | **37.3802** | **7.9001** | **0.8001** |

## VI. CONCLUSION

In remote sensing, the problem of image fusion deals with the problem of fusing important information from many input sensors operating in a variety of spectral bands into a single fused image that has high spatial as well as high spectral resolutions. The IHS-FTR transformations based fusion of Ms and Pan image is proposed. Experimental results prove that the fused images obtained from the proposed algorithm contain both high spectral information of Ms image as well as high spatial details of the Pan image.

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