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Evaluation of Fusion Techniques for High Resolution Data - A Worldview-2 Imagery

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Abstract

Both the visible and infrared pictures provided by the high-resolution satellite have their own limitations in terms of spatial and spectral resolution. There is no picture that combines the two qualities. Therefore, an image fusion method may be used to combine both features into a single picture. Image fusion improves the image's analytical and aesthetic qualities. Panchromatic and multispectral images may be fused using a variety of methods. In order to determine the best method for fusing WorldView-2 images, this research employs four distinct fusion approaches. There are a variety of assessment factors that may be utilized to zero in on the fusion technique that works best with WorldView-2 data. All aspects of the fused picture, including its spatial, spectral, and statistical properties, were taken into account by the assessment techniques. Visual evaluation of the combined photos is included in this research. When comparing panchromatic and multispectral photos, as well as evaluating the fused images using a variety of parameters, the HPF fusion approach is shown to be the most relativistic and to maintain the most characteristics of the original images. So, it is the optimal fusion method for WorldView-2 pictures.

Keywords: *Abbreviations: NDVI, LST, Brightness Temperature; LSE, FVC, Landsat.*

1. **Introduction**
2. The World View series, the GeoEye series, the Pleiades series, etc., are only a few examples of today's high-resolution remote sensing satellites. All of them are capable of capturing a high-resolution picture in either panchromatic or multispectral modes. The first one is grayscale but full of spatial detail. The second one is a decent spectral picture, but lacks the spatial detail of the first.
3. Therefore, it seems challenging to get the picture with both high spatial and spectral resolutions using the same data. In such case, it's best to combine the two photos into one. In order to increase the reliability of information extraction and the visual and analytical quality of the resulting picture, the two images are fused into a single, combined image using spatial and spectral information. The purpose of fusing images is to prevent any data loss while keeping both the spatial information from the panchromatic picture and the spectral information from the multispectral image.
4. The variety of fusion methods available is extensive. Popular fusion methods include PCA, Brovey

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Vol-3 Issue-02 April 2015

transform, IHS transform, HPF, etc. The aforementioned techniques may increase spatial resolution and spectrum information preservation by fusing multispectral photos with high resolution images.

5. Here, several fusion methods are used to produce a single picture that optimally combines the spatial and spectral details of the original images. There are benefits and drawbacks to each option. As a result, this study employs a variety of assessment strategies to assess the efficacy of fusion procedures.

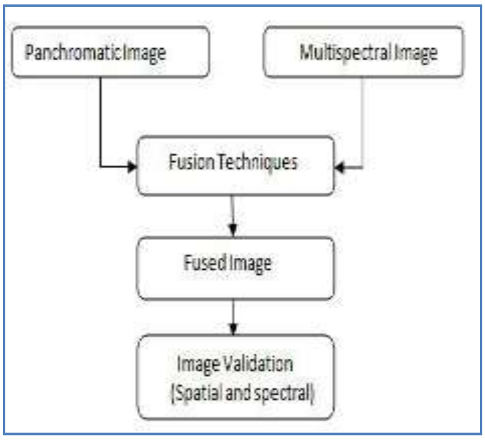

Figure 1: Fusion approach.

6. Datasets and Methods

6.1 Datasets

In this study WorldView-2 imagery of Chandigarh city, India is considered. Datasetwas acquired on 08 May 2013. It is georeferenced in the WGS84 coordinates system and it is included between coordinates 76.7590110000E – 76.936617E and 30.7979910N – 30.644000999N. The panchromatic as well as multispectral imageof the study area is considered in this study.The Panchromatic sensor have a spatialresolution of 0.46m at nadir and 0.52m at 20°off-nadir while multispectral have a spatialresolution 1.85m at nadir and 2.07m at 20°off-nadir. The spectral interval of Pan andmultispectral bands are:

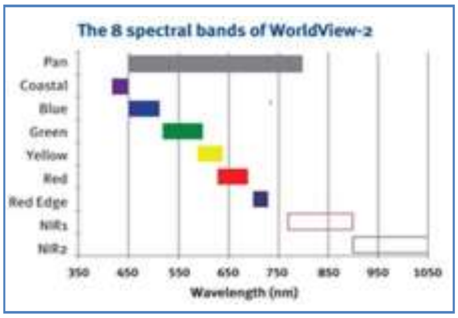

Figure1: Spectral bands of WorldView-2

The higher spatial resolution as well as availability of 8 bands makes WorldView-2 very useful for GIS related applications. In fact they can integrate a geodatabase, so to contribute to define the different representations (scale, time) of the same geographic entities and relationships as well as support object identification.

6.2 Fusion algorithms

A plethora of picture fusion algorithms have been created during the last several decades. The fusing of high-resolution data may be accomplished with a wide variety of fusion techniques, such as Principal component analysis, HPF resolution merge, Brovey, HCS resolution merge, Ehlers fusion, and many more. Evaluation of Fusion Techniques... many criteria for fusing pictures, as well as the pros and cons of certain fusion techniques. This research takes a look at four different fusion methods to evaluate how well they work with high-resolution images. In this research, we employed four different fusion algorithms: the Ehlers fusion algorithm, the Resolution Merge (PCA) methodology, the HPF Fusion program, and the Hyperspherical Color space algorithm. (Some excellent fusion procedures, such as the IHS method, only make use of three bands in the final picture because of their technological restrictions. Due to the eight-band nature of the research area picture, the employment of fusion methods of this kind has been avoided.

The ideas and beliefs that underpin

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Vol-3 Issue-02 April 2015

fusion algorithms are following:

a) **Ehlers Fusion:** The Ehlers fusion is based on an IHS transform coupled with a Fourier domain filtering. This technique is extended to include more than 3 bands by using multiple IHS transforms until the number of bands is exhausted. A subsequent Fourier transform of the intensity component and the panchromatic image allows an adaptive filter design in the frequency domain. Using fast Fourier transform (FFT) techniques, the spatial components to be enhanced or suppressed can be directly accessed. The intensity spectrum is filtered with a low pass filter (LP) whereas the panchromatic spectrum is filtered with an inverse high pass filter (HP). After filtering, the images are transformed back into the spatial domain with an inverse FFT and added together to form a fused intensity component with the low-frequency information from the low resolution multispectral image and the high-frequency information from the high resolution image. This new intensity component and the original hue and saturation components of the multispectral image form a new IHS image. As the last step, an inverse IHS transformation produces a fused RGB image. These steps can be repeated with successive

3-band selections until all bands are fused with the panchromatic image. The Ehlers fusion shows the best spectral preservation but also the highest computation time [2].

b) **Hyperspherical Colour Space (HCS):** Hyperspherical Colour Space is designed for WorldView-2 sensor 8-band data, and works with any multispectral data containing 3 bands or more. This technique combines high-resolution panchromaticdata with lower resolution multispectral datausing the Hyperspherical Colour Sharpening algorithm. Data is transformed from native color space to hyperspherical color space. There are two modes of operation of HCS pan sharpening algorithm. The first mode is called the naïve mode and simply replaces the multi-spectral intensity component with an intensity matched version of pan band. Naïve mode has the advantage that it is simple to implement. Generally this provides a sharp image but some color distortion is noticeable in the resulting pan-sharpened image, as we are assuming that each multispectral band contributes equally to panchromatic intensity. The second mode is called smart mode. It has been observed that this mode does an acceptable job of replicating the original multispectral colors. The reason for this is that this mode models the difference between the pan and the multispectral intensity and accounts for thisdifference during the pan sharpening process while naïve mode does not [6].

c) **HPF Resolution Merge:** The HPF resolution merge function allows combining high-resolution panchromatic data with lower resolution multispectral data, resulting in an output with both excellent detail and a realistic representation of original multispectral scene colors. In the HPF method the higher spatial resolution data, have a small high

ISSN: 1832-5505
Vol-3 Issue-02 April 2015

pass filter applied. The results of small high pass filter contain the

high frequency component/information that is related mostly to spatial information. The spatial filter removes most of the spectral information. The HPF results are added, pixelby pixel, to the lower spatial information, but the higher spectral information dataset. This process merges the spatial information of the higher spatial resolution dataset with the spectral information of the higher spectralresolution dataset.

d) Resolution Merge (Principal Component Analysis): The Principal Component Analysis (PCA) is a statistical technique that transforms a multivariate dataset of correlated variables into a dataset of new uncorrelated linear combinations of the original variables. It is assumed that the first PC image with the highest variance contains the most amount of information from the original image and will be the ideal choice to replace the high spatial resolution panchromatic image. All the other multispectral bands are unaltered. An inverse PCA transform is performed on the modified panchromatic and multispectral images to obtain a high-resolution pan-sharpened image.

7. Quality Assessment Criteria

The quality of images refers to its spatial and spectral quality and somewhat statistical parameters also. The multispectral image has the tremendous spectral content and the panchromatic image has fine spatial information. But both the images have their limitations, which is overcome by fusion techniques. The main aim of using fusion algorithms is to enhance the spatial quality of the multispectral image without degrading its spectral content. So, four different fusion algorithms are used to get the desired fusion results.

Now, for evaluating which fusion technique gives the desired output, some quality assessment criteria are applied on each

fusion techniques. The criteria of assessment is qualitative as well as quantitative, it includes visual inspection/interpretation, spectral, spatial and statistical properties and definition of images also.

In this study, six evaluation techniques have been used for the spatial and spectral quality assessment of fused images. The spectral quality of fused images is evaluated using the spectral discrepancy, Correlation coefficient (CC), Per Pixel Deviation (PPD) and Root mean square error (RMSE) methods. For spatial quality assessment, edge detection and High pass filtering are applied.

7.1 Spectral Quality Assessment

The basic principle of spectral fidelity is that the low spatial frequency information in the high-resolution image should not be absorbed to the fusion image, so as to preserve the spectral content of original MS image. The processes which can inflect the spectral fidelity of fusion image include:

a.) Correlation Coefficient: CC measures the correlation between the original and the fused images. The higher the correlation between the fused and the original images, the better the estimation of the spectral values. The ideal value of correlation coefficient is 1 [12].

b.) Per Pixel Deviation: For a per-pixel deviation (PD), it is necessary to

ISSN: 1832-5505
Vol-3 Issue-02 April 2015

degrade thefused image to the spatial resolution of the original image. This image is then subtracted from the original image on a per-pixel basis. As final step, the standard deviation is calculated. Here, zero is the best value [1] [2]. **c.) Root Mean Square Error (RMSE)** - RMS error as proposed by Wald (2002), whichis computed as the difference of the standard deviation and the mean of the fused and the original image. The formula forRMSE is:
Evaluation of Fusion Techniques...

RMSE= **(1)**

σ=

bias = a

σ is standard deviation, x is mean, org is original image and fused is fused image.
d.) Spectral Discrepancy (SD): The spectral quality of an M x N fused image can be measured by the discrepancy at eachband.

D —Σ Σ |F x,y L x,y |,k **(2)**

WhereF x, y and L x, y are the pixel values of the fused and original multispectral images at position (x, y), respectively [3].

7.2 Spatial Quality Assessment

The basic principle of spatial fidelity is that the high spatial frequency information absorption is the enhancement of resolution and increasing of information of the fused image relative to the original MS image. The processes which can inflect the spatial fidelity of fusion image include:

a) **High Pass Correlation:** For the spatial quality of image, the high frequency data from the panchromatic image to the high frequency data from each band of the fused image are compared. To get the high frequency data, high pass filter is used on both images. The high pass filter is applied to the panchromatic image and each band ofthe fused image. Then the correlation coefficients between the high pass filtered fused images and the high pass filtered panchromatic image are calculated.
The correlation coefficients between the
high-pass filtered fusion results and the high-pass filtered panchromatic image is used as an index of the spatial quality. The principle is that the spatial information unique in panchromatic image is mostly

concentrated in the high frequency domain. The higher correlation between the high frequency components of fusion result and the high frequency component of panchromatic image indicates that more spatial information from panchromaticimage has been injected into the fusion result [3].

b) **Edge Detection:** Edge detection (ED) in the panchromatic image and the fused multispectral bands: For this, a Sobel filter is selected [7] and performed a visual analysis of the correspondence of edges detected in the panchromatic and the fused multispectral images. This was done independently for each band. The value is given in percent and varies between 0 and
100. 100% means that all the edges in the panchromatic image were detected in the fused image [2].

7.3 Visual Interpretation

The quality of fused image is also

assessing by visual interpretation. The parameters for visual interpretation are sharp edges, texture of image, color shadow, shape etc. The visual interpretation of image is subjective and it depends on interpreter.

7.4 Statistical Quality Assessment

The statistical values of image are used to measure the color preservation of image. The statistical parameters like mean, mode, median and standard deviation are used to evaluate (or compare) the images; like standard deviation indirectly shows the brightness values of the image and mean describes the position of data or point where DN histogram curve positioned horizontally.

4. Evaluation of Fusion methods

The objective of fusion is to achieve spatial information of panchromatic image as well as spectral information of multispectral image in one single image. To achieve this goal, lots of fusion techniques are evolved in last few decades. In this study, four different

fusion techniques are used to achieve the above mentioned objective. All four fusion techniques have different approach regarding fusion, as described in above paragraph. The output image from each fusion techniques is somewhat different in term of spectral and spatial information, although the input images are same for each one. They have their advantages and disadvantages with respect to fusion. Now, it is very difficult to say that which fusion technique is better. So, evaluation of fusion techniques is required on the basis of spatial and spectral property of fused image. The evaluation parameters or methods used for evaluating the fused image on the basis of spatial, spectral, visual and statistical property are describe. The implementations of those evaluation parameters are described here.

4.1 Spatial Quality Evaluation

The spatial property of fused image is analyzed on the basis of high pass correlation and edge detection parameters. The principles behind these two parameters are described in previous section.

High Pass Correlation: The principle for spatial data is that the spatial information in panchromatic image is unique and mostly concentrated in high frequency domain. So for evaluating the spatial quality of the fused image, it is required to compare the high frequency data of panchromatic image and high frequency data of fused image. Both image has high as well as low frequency data, so for comparison of high frequency data, it is required to enhance the high frequency data or remove the low frequency data. For this, high pass filter is applied on the both images. The high pass filter is applied to the panchromatic image and each band of the fused image. Then the correlation coefficients between the high

pass filtered fused images and the high pass filtered panchromatic image are calculated. The correlation coefficients between the high-pass filtered fusion results and the high-pass filtered panchromatic image is used as an index of the spatial quality. This index is used to evaluate that which fusion technique has better spatial information. The result and graphs or plots regarding high pass correlation is described in result and discussion section [3].

a) **Edge Detection:** The second parameter for evaluation of spatial

ISSN: 1832-5505
Vol-3 Issue-02 April 2015

information of fused image is edge detection. The edges of objects shown in panchromatic image are easily differentiable due high spatial information. So, for comparing the edges of panchromatic imageand fused image, Sobel filter is used. The Sobel filter enhances the edges of objects in the images and suppresses other information in the objects. The Sobel filter isapplied on panchromatic image and each band of fussed image. This was done independently for each band. The value is given in percent and varies between 0 and
100. 100% means that all the edges in the
panchromatic image were detected in the fused image (as edge detection is totally based on visual analysis of the viewer, an offset of 10% is taken in this study to minimize the chance of errors in our results. The visual analysis of the correspondence of edges detected in the panchromatic and the fused multispectral images has been done).

4.2 SPECTRAL QUALITY EVALUATION

In spectral quality evaluation of fused image four different parameters or evaluation methods are used, which is described in theoretical approach. The implementation of those evaluation parameters are described in following paragraph.

a) **Correlation Coefficient:** The correlation coefficients of spectral values of

images play a significant role in their spectral property. So, the correlation coefficient of fused image and original multispectral image helps in evaluation of fusion techniques. For calculating the correlation coefficient of fused image and multispectral image, the pixels values of each band of bothimages are collected in tabular form. Then correlation coefficient of each pixel of each band of both images are calculated through statistical formula in excel sheet. The result and plots for each fusion technique is discussed and shown in result and discussionsection.

b) **Per Pixel Deviation:** After the process of fusion, the spatial resolution of fused image is equal to the panchromatic image. But the spectral property is somewhat equal to multispectral image. But the pixel size of fused image and original multispectral image is different, so it will become difficult to evaluate the spectral property of fused image. The solution for this problem is to resample the fused image to spatial resolution of original multispectral image. After resampling the fused image, the fused image is subtracted from original image to check the deviation of pixel values in fused image. For subtracting the fused image from original image, the operator tool is used and subtraction is taken for this procedure. The pixel values of output image are converted into tabular form and per pixel deviation of each band is calculated throughthe standard deviation between each band image. A graph is plotted between per pixeldeviation of all fused images. The result and graphs or plots are discussed in result and discussion section.

c) **Root Mean Square Error:** The root
mean square error is calculated to find out the error between the fused image and original multispectral image. For calculating the RMS error of images, a

formula is derivedby Wald as described in theoretical approach. The RMS error is calculated on perpixel basis for each band of image. As per the formula adopted for RMS error, the standard deviation for each band of fused images is calculated with respect to the original image. The mean of original image and fused image is calculated for each band. Now, the mean of fused image is subtracted from mean of original image. The next step for calculating RMS error is to take sum of standard deviation of fused image and original image and take square of that sum and take square resultant mean(resultant mean is result got after subtraction of mean value of originaland fused image). The last step is to take sumof both resultant standard deviation and resultant mean and take square root of this sum. The results and graph plot is discussedin result and discussion section.

d) **Spectral discrepancy:** The spectral discrepancy of fused image is calculated through the mean of sum of the difference of all the pixel values of the image of the same location. It is calculate through the formula mentioned in quality assessment criteria section. For calculating the spectral discrepancy of fused image, the pixel values of fused image is subtracted from original one. Now, an image is prepared from those pixel values and mean of each pixel values of each band is taken and plotted as a spectral discrepancy.

The evaluation of fused image is done through visual interpretation also. The visual interpretation is based on the eight elementsof visual interpretation, which are shape, size, pattern, tone, texture, shadows, site and association (sometime resolution is alsocounted). The visual interpretation is highly subjective, because it depends on the experience and knowledge of interpreter. The statistical values of fused image are also compared with original images. The

statistical values of fused image is calculated simply from the pixel value of image in excel sheets and plotted through some graphs.

5. Results and discussion

The evaluation of fusion techniques has been done in previous paragraphs throughdifferent parameters like spatial, spectral, visual and statistical properties of image. After the evaluation of fusion techniques through above mentioned techniques, the result of evaluation is discussed in followingparagraphs.

The initial qualitative inspections of fused images show that the fused images have better qualifications than original images. The sharpness of the fused images has been significantly enhanced. The further quantitative evaluation can be done through above mentioned quality assessment criteria.

Visual Analysis of Fused Images- The fused images was evaluated visually for spatial and spectral resolutions. The images in Figure 2 show that the spatial and the spectral resolutions are improved, in comparison to the original images.

The fused images contain both the fine structural details of the higher spatial resolution panchromatic image and the richspectral information from the multispectral image. The colors of the features in the fused images have changed. This color distortioneffect is the largest in Ehlers method followed

Applied GIS
ISSN: 1832-5505
Vol-3 Issue-02 April 2015

by resolution merge (PCA), HCA method and HPF techniques. Among the four methods, HCA and HPF give the best result in terms of color conservation. The spectral characteristics of HPF fusion and Resolution Merge–PCA are closest to the original multi- spectral image than other fused images. The HPF and HCA techniques give a better spatial resolution when compared to other fusion methods.

So the overall visual interpretation of fused images clearly indicates that the HPF fusion method shows maximum relativity with original image in terms of spectral property and spatial property is also enhanced in comparison to other fused images. The colordistortion is minimum in HPF fused image.

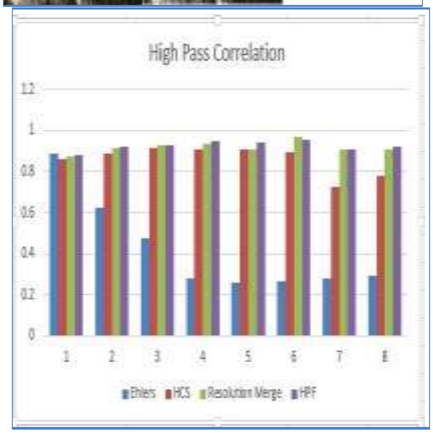

Figure 4 shows the edge detection

Figure 2 Fused images (i) Original image (ii) Ehlers fused image (iii)HPF fused image (iv) HCSfused image (v) Resolution merge(PCA).(from left to right).

i) Spatial Quality Assessment-

The results of spatial quality assessment for evaluation of fused images are following.Figure 3 shows the correlation coefficient between high pass filtered fused images andhigh pass filtered panchromatic image, HPF

is highest (avg. value is 92.6%), Resolution merge (PCA) is second (avg. value is 91.86%), HCS (avg. value is 86.01%) is the third and Ehlers(avg. value is 41.82%) is the lowest. This indicates that HPF and Resolution Merge

fusion results are injected into the most spatial information, while the Ehlers fusion result is injected into the least.

Figure 3: High Pass correlation between original panchromatic image and fused image

percentage of each band of the

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Vol-3 Issue-02 April 2015

multispectral image from different fusion algorithm. It clearly indicates that the HCS fusion method (avg. value is 81.81) are very good for edge detection in comparison to other fusionalgorithm, Ehlers fusion method (avg. value is 79.25%) and HPF fusion method (avg. value 80.44%) is also very good in edge detection and very near to HCS fusion algorithm.

ISSN: 1832-5505
Vol-3 Issue-02 April 2015

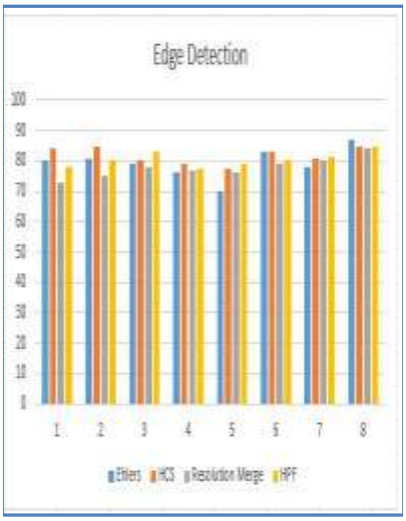
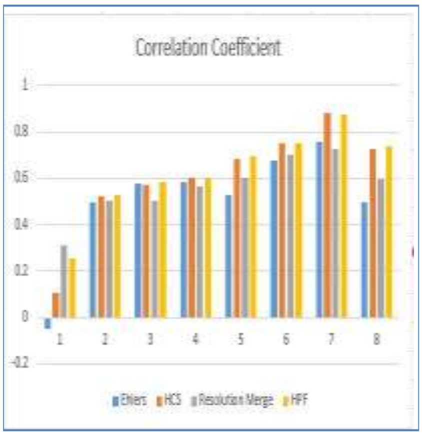


Figure 4 Edge accordance of fused images with panchromatic image\

Spectral Quality Assessment- The results of spectral quality

Figure6 shows that the spectral discrepancies between the images obtained by different fusion algorithms and the source multispectral image. It clearly indicates that the discrepancy of Resolution Merge (avg.value is 11.98%) is the minimum, anddiscrepancies of HPF (avg. value 13.95%) is

the further minimum. So Resolution Merge isthe best method in retaining



spectral property of the original image among the four used methods and HPF fusion method (avg. value is 13.95%) takes second place.

assessment forevaluation of fusion results are following. Figure5 shows the HCS fusion algorithm(avg. value is 61%) and HPF fusion algorithm(avg. value is 63%) has approximately samecorrelation coefficient, which is highest. So,as per quantitative analysis, HCS and HPF fusion algorithms are the best that means

preserve the spectral characteristics of the original(or s

Figure 5: Correlation Coefficient between original multispectral image and fusion results

ISSN: 1832-5505
Vol-3 Issue-02 April 2015

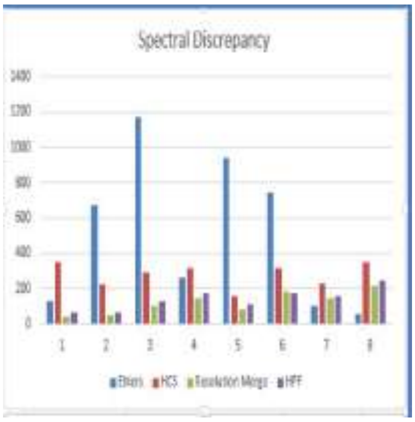


Figure 6: Spectral discrepancy between original multispectral image and fusion results

Figure7 shows that the Per Pixel deviation between the images obtained by the different fusion algorithms (after resampling it) and the original multispectral image. It clearly indicates that per pixel deviation of HPF (avg. value is 33.42%) is minimum in all fusion methods and the resolution merge (avg. value is 47.60%) takes second place in deviation.

Evaluation of Fusion Techniques…

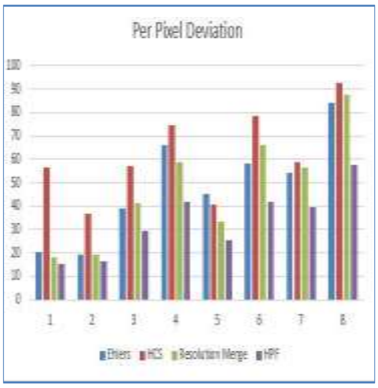


Figure 7 Per pixel deviation between original multispectral image and fusion results Figure8 shows that the RMS error of fusedimage with respect of original multispectralimage. It clearly indicates that the Resolution Merge (PCA) has minimum RMS error and HPF has slightly more RMS error in comparison of Resolution Merge.

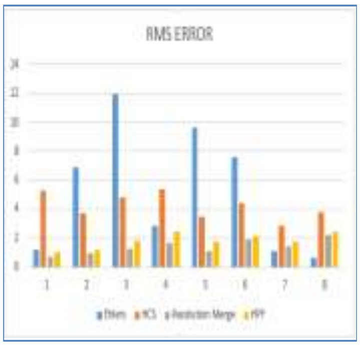


Figure 8: RMS Error between original multispectral image and fused resultsAccording to the above results of spectral quality assessment, it is finding that the HPF-fused image has the maximal relativity withoriginal multispectral image. So HPF fusionalgorithm is the best method in retaining spectral property of the original image among the four used methods.

Statistical Evaluation

Statistical metrics such as mean, median, mode, standard deviation, etc. are used in the statistical assessment of the photographs. Only the mean and the standard deviation are utilized to compare the fused and original pictures to one another.

If you imagine a histogram of DN values, the horizontal axis across the center of the histogram represents the mean. Figure 9 demonstrates that among the fused pictures, the one produced by using the Resolution Merge (PCA) approach has the lowest mean values. An picture created using HPF and HCS is almost as valuable as the original multiband image. The mean value of each band is low in the resolution merging picture, making the resulting image somewhat darker than others that have been fused. When compared to the original picture, the Ehlers fused image has higher mean values, making it look brighter.

The standard deviation is a statistical measure that follows the mean. The brightness values of a picture are shown

ISSN: 1832-5505
Vol-3 Issue-02 April 2015

by the difference between the pixel values of the original and fused images. As can be seen in Figure10, the standard deviation values of the HPF fusion technique are much closer to those of the multispectral image than those of the other fusion methods. Family Ehlers

There is less brightness variation in the fused picture since the standard deviation is less.

As a consequence, the HPF fusion algorithm outperforms competing methods by a wide margin, demonstrating the highest degree of similarity to the original multispectral and panchromatic pictures.

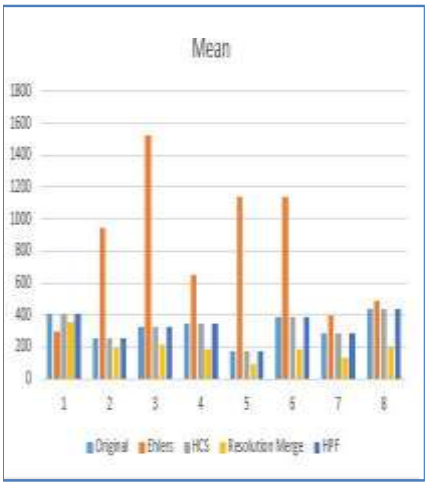


Figure 9: Mean values of fused and original multispectral images.

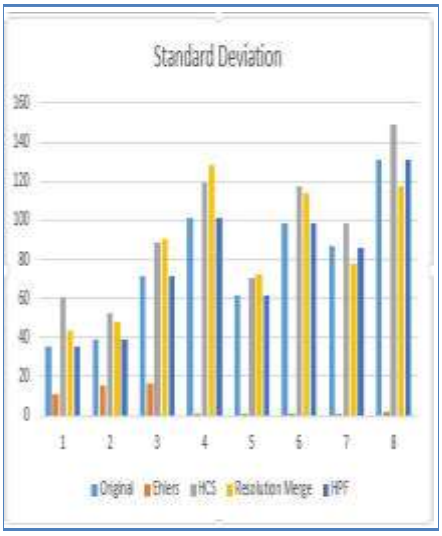


Figure 10 Standard deviation values of fused and original multispectral images.

Conclusion

The results and analysis of evaluation techniques show that the HPF fusion method has maximum relativity withpanchromatic and multispectral images and it retains maximum properties of original images in fused image.

Evaluation of Fusion Techniques...

This study proposed a new approach for fusion of high resolution data and evaluatingthe fused data through different parameters of image quality. This study proves that the

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The examination of fusion methods is crucial to determining which one is best for the user.

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