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Image Fusion Techniques and Measurement to Assess the Image Quality

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Abstract: *Image processing techniques focus upon enhancing the quality of an image or set of images and to derive maximum information from them, producing a superior quality image from a set of available images. Image Processing is a computer imaging where application involves a human being in the visual loop. Information fusion is a naturally occurring phenomenon in the most biological system. Data from various sources are merged in order to make optimal decision. In field of remote sensing, satellite image are captured in various frequency bands with different spatial, temporal and spectral reslutions. Remote sensing data is useful in various application from monitoring growth of vegetation to detection of geographical infiltration.*

Keywords: Image Fusion, Wavelength, HIS, PCA, DWT.

I. INTRODUCTION

A. The Wavelength spectrum

The majority of remote sensing is done with passive sensors, for which sun is a major source the earliest example of this is photography with the airborne cameras we have long been able to measure and record the reflection of light off earth features.

B. Wavelength

Most Remote sensing devices make use of electromagnetic energy. However, the electromagnetic spectrum is very board and not all wavelength are equally effective for remote sensing purpose .Furthermore, not all significant interaction with earth surface materials of interest to us.

C. Spectral Response Patterns

The eye is able to sense spectral response patterns because it is truly a multi-spectral sensor(i.e., it senses in more than one place in the spectrum).Although the actual functioning of the eye is quite complex, it does in fact have three separate types of detectors that can usefully be thought of as responding to the red, gree, and blue wavelength regions. In the early days of remote sensing ,it was believed that each earth surface material would have a distinctive spectral response pattern that would allow it to be reliably detected by visual or digital means. However as ,our common experience with colour would suggest, in reality this is often not the case. For example, two species of trees may have quite a different coloration at one time of the year and quite a similar one at another. Finding distinctive spectral response patterns is the key to most procedures for computer-assisted interpretation of remotely sensed imagery.

D. Image Processing

Image Processing techniques primarily focus upon enhancing the quality of image or set of images and to derive the maximum information from them. Image Fusion is such a technique of producing a superior quality image from a set of available images. It is a process of combining relevant information from two or more images into a single image where in the resulting image will be more informative and complete than any of the input images. A lot of research is being done in this field encompassing areas of Computer Vision ,Automatic object detection, Image processing, parallel and distributed processing, Robotics and remote sensing.

Image Fusion is an effort to merge relevant visual data sets which are dependent and yet have a disparity to certain extent in order to come up with a smaller data set apt for a better semantic interpretation of data for a given application. In the field of remote sensing, satellite images are captured in various frequency bands with different spatial, temporal and spectral resolution. The data acquired from all these sources have a disparity in nature and images of same location have spatial dependency .The situation is exploited by image fusion algorithms to come up with merged images which are more detailed and information-rich than any of the individual images.

The usefulness of remote sensing data is only as good as its use in the required application.If the resolution of the captured data is too low or the distortion in the data is too high, the data may be of no use in any application Unfortunately in real world condition the resolution and distortion are generally worse than what the orginal hardware was designed for or what is required of a given applications. Image fusion plays a very important role in such cases.It is able to convert a combination of such data sets with low information content to a single data set with low information content to a single data set of higher information content.

II. LITERATURE REVIEW

A. Processing levels of Image Fusion

Fusion of images is a process of identifying useful information content and combining them efficiently to make the final image more meaningful for a particular application .Depending on the level at which the classification of useful data is done, images may be fused at the different levels which includes signal level, pixel level, feature level and decision level. Fusion of some redundant data from different sensors is generally done to improve the signal level fusion. Diversity combining is another kind of a signal level fusion.

Techniques such as principal component analysis and multi-resolution analysis extract details of an image and perform fusion in a different domain .This leads to enhancement of the image along the required components of the image. Thus, to certain extent ,this involves recognition of distinct features in the image. These features may not correspond to any particular spatial features but are generally at a border scale than pixels. Feature level fusion requires individual features to be identified by object recognition schemes. Decision level fusion occurs at higher levels of abstractions by combining results from multiple algorithms to yield a final fused decision.

III. IMAGE FUSION USING MATLAB

A. Product Perspective

The image fusion approach application is aimed towards the providing an image which is a fusion of 2 or more images retaining the important features from each of the image .MATLAB is a high level language and interactive environment for numerical computation, visualization and programming .Using MATLAB you can analyze data, develop algorithms and create models and applications. The language, tools, and built-in math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages such as c/c++ or java.

B. Product Functions

The primary function of the product is to provide Multi Resolution Image Fusion based on wavelet transforms and PCA transform. The product is developed as MATLAB programming language.

IV. FUSION OF IMAGE TO ASSESS THE IMAGE

A. Fusion of Images to Assess the Image Quality

Detailed design of the proposed multi spectral image fusion approach work gives in depth picture of the most components described in the system architecture diagrams.

The control flow is shown by the structure chart ,the functional description of which are presented in the flow chart .

- Wavelet Based Image Fusion
- Haarwavlet transfrom(DWT)
- Inverse Haar wavelet transforms(IDWT)
- Multi spectral Image Fusion

- PCA Based Image Fusion
- Generation of principle components
- Pca2rgb space transformation
- Components fusion for enhancement

B. Structure Chart

Structured flow chart gives overall strategy for structuring project. It gives details about each module evolve during detail design and coding. The modules and their design for this specific application are as shown in diagram.

A structure chart depicts

- The size and complexity of the system.
- Number of readily identifiable functions and modules within each function.
- Whether each identifiable function is a manageable entity or should be broken down into smaller components. Structure chart of wavelet image fusion. In the fusion methods based on wavelet transform, the A structure chart is also used to associate the elements that comprise a run stream or thread. It is often developed as a hierarchical diagram, but other representations are allowable. The representation must describe the breakdown of the configuration system into subsystems and the lowest manageable level. The structure chart of the project is as shown in the figure A and B

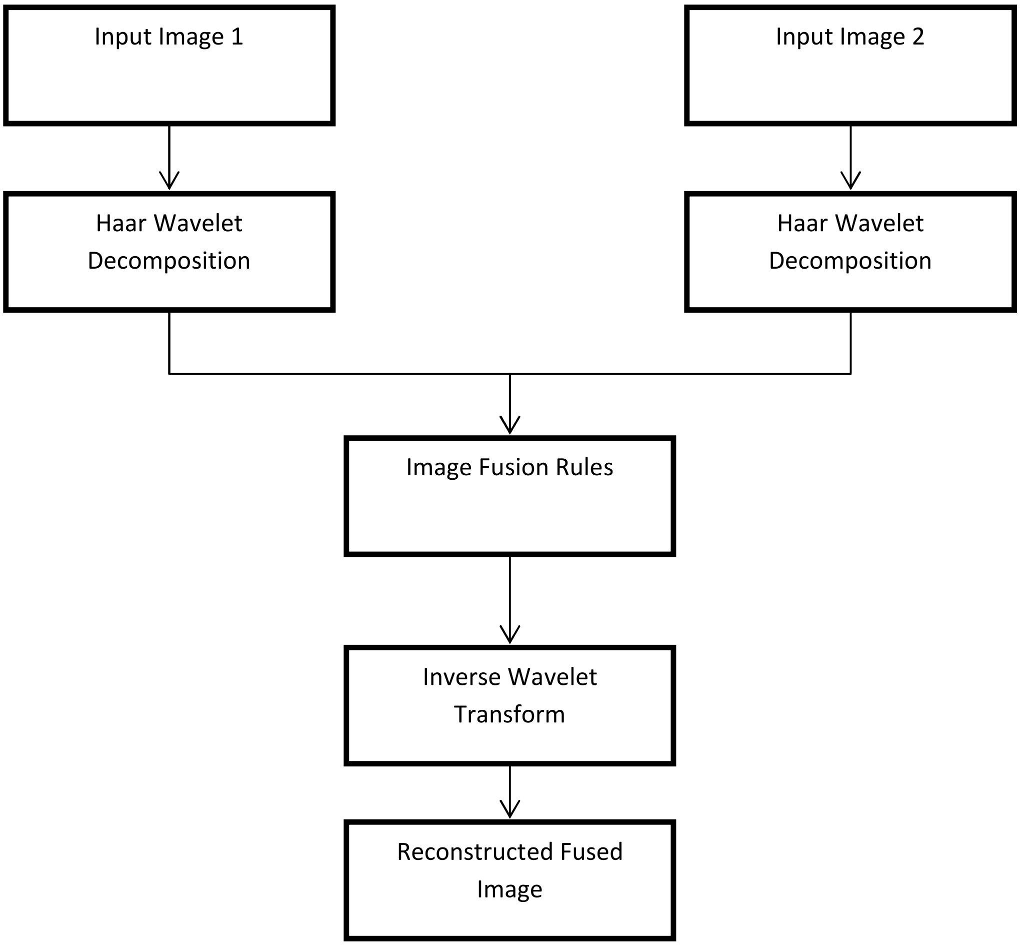

Figure A: Structure chart of wavelet image fusion

Figure A shows images are decomposed into pyramid domain, in which coefficients are selected to be fused. The two source images are first decomposed using wavelet transform. Wavelet coefficients from MS approximation subband and PAN detail subbands are then combined together, and the fused image is reconstructed by performing the inverse wavelet transform. Since the distribution of coefficients in the detail subbands have mean zero, the fusion result does not change the radiometry of the original Multi spectral image. The simplest method is based on the selection of the higher value coefficients, but various other methods have been proposed in the literature

Figure B shows Structure chart of PCA Based Image Fusion.PCA is a general statistical technique that transforms multivariate data with correlated variables into one with uncorrelated variables. These new variables are obtained as linear combinations of the original variables. PCA has been widely used in image encoding, image data compression, image enhancement and image fusion. In the fusion process, PCA method generates uncorrelated images (PC1, PC2…PCn, where n is the number of input multispectral bands). The first principal component (PC1) is replaced with the panchromatic band, which has higher spatial resolution than the multispectral images. Afterwards, the inverse PCA transformation is applied to obtain the image in the RGB color model.

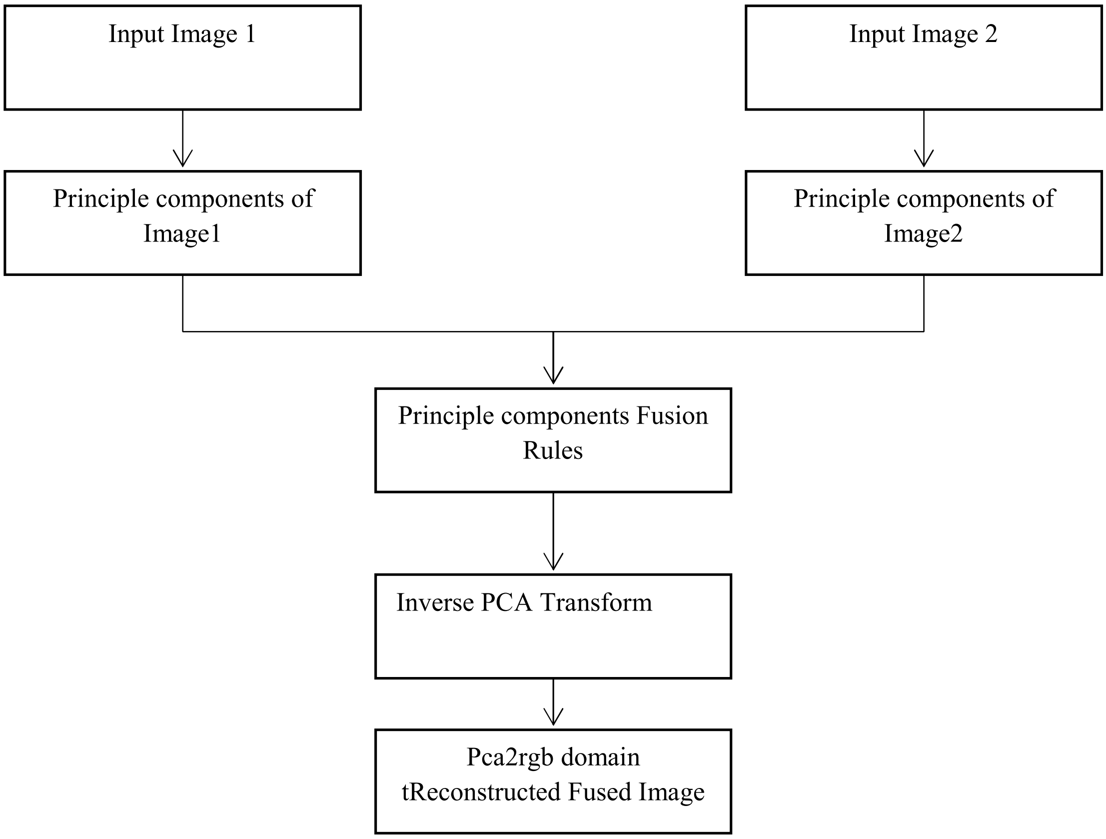

Figure B Structure chart of PCA Based Image Fusion.

C. Flow Charts

Wavelet Based Image Fusion

Figure C shows Flow chart of Image Fusion based on wavelet Transform .A flow chart is common type of notation that represents an algorithm or process, this diagrammatic representation give a step-by-step solution to a given problem. Flow charts are used in analyzing, designing, documenting or managing a process or program in various fields.

The flow Chart is divided into Blocks A, B, C and D block.

Block A

Two images act as an input. The Two images are compared and evaluated. If the images are matched then they are processed for Block B. If the images are not matched an error message is obtained.

Block B

The matched images are transformed into the wavelet domain.

Block C

In the wavelet domain choose the maximum co-efficient. The next function is the consistency function. The images are checked for the consistency. If the images are not consistent then consistency function is applied. If the images are consistent then the images are entered into the Block D.

Block D

The consistent image is next entered into the Block D. In Block D, the images are subjected to inverse wavelet transform. In this way the images are fused

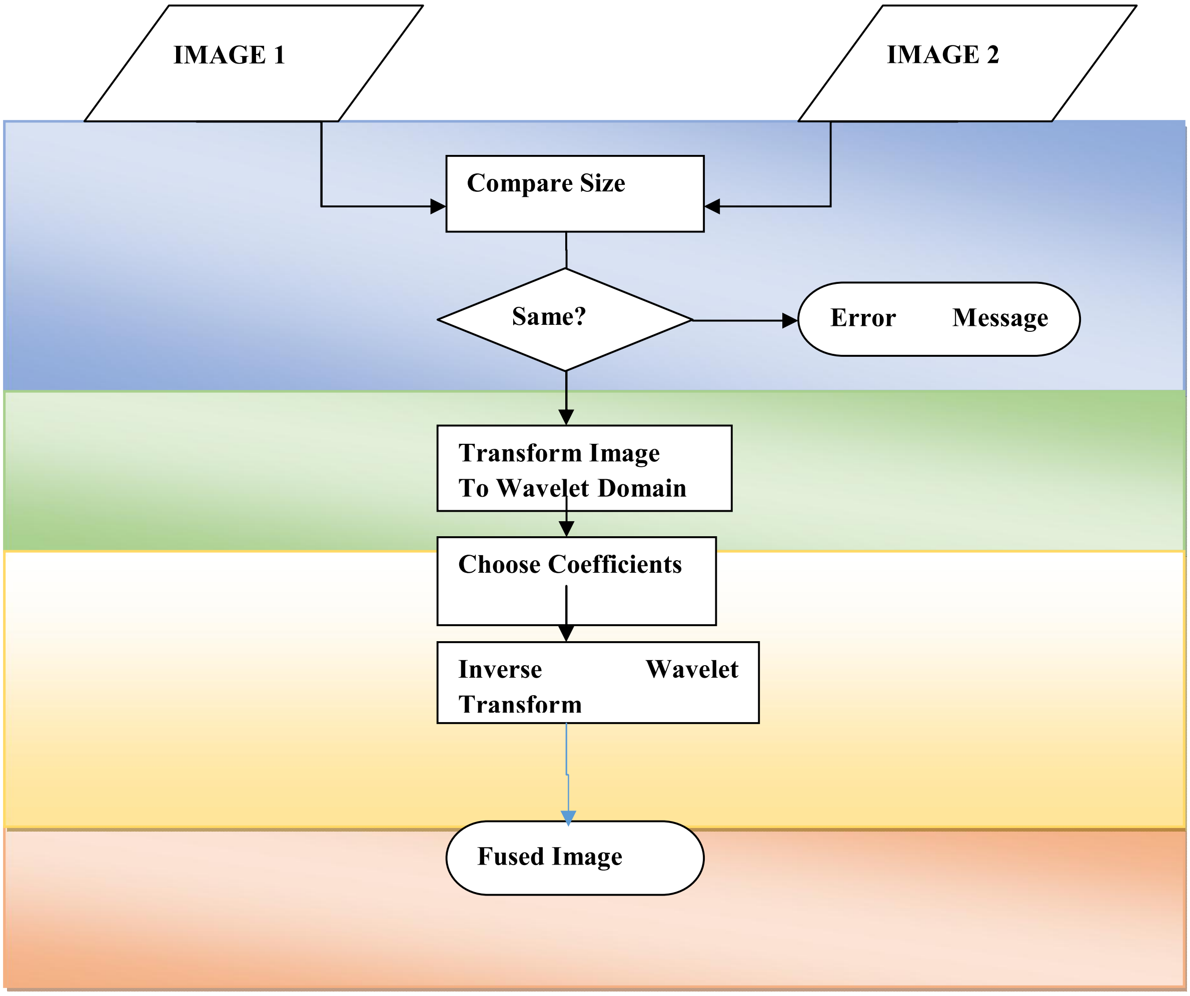

Figure C Flow chart of Image Fusion based on wavelet Transform

PCA Based Image Fusion

Figure 1 Flow chart of Image Fusion based on PCAThe flow Chart for Laplacian Based Image Fusion is divided into Blocks A, B, C and D block.

Block A

2 images act as an input. The 2 images are compared and evaluated. If the images are matched then they are processed for Block B. If the images are not matched an error message is obtained.

Block B

The matched images are transformed into the PCA Domain.

Block C

In the PCA Domain select luminance PCA component. The next function is the consistency function. The images are checked for the consistency. If the images are not consistent then consistency function is applied. If the images are consistent then the images are entered into the Block D.

Block D

The consistent image is next entered into the Block D. In Block D, the images are subjected to inverse PCA. In this way the images are fused.

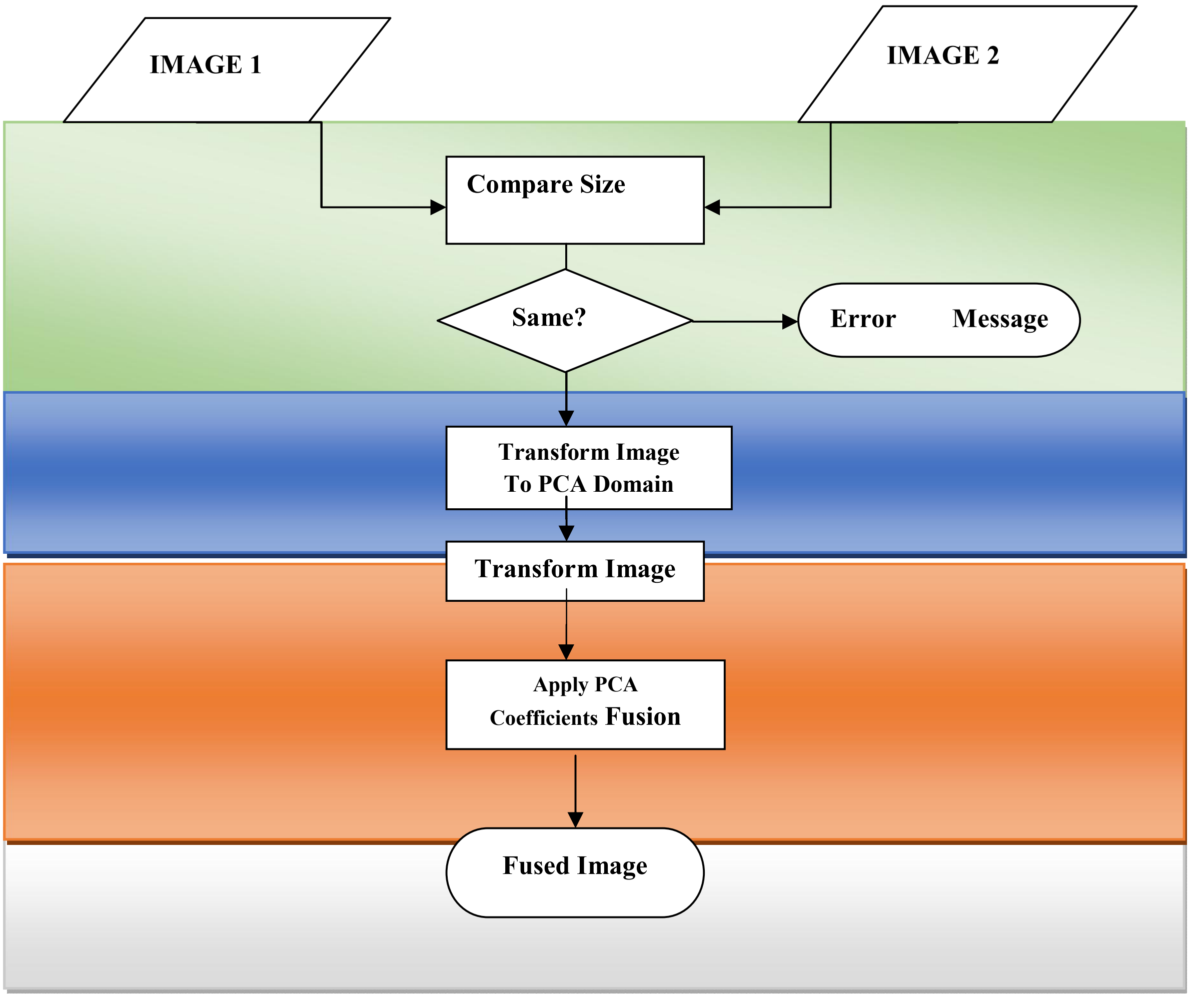

Figure 1 Flow chart of Image Fusion based on PCA.

D. Block Diagram of System Design

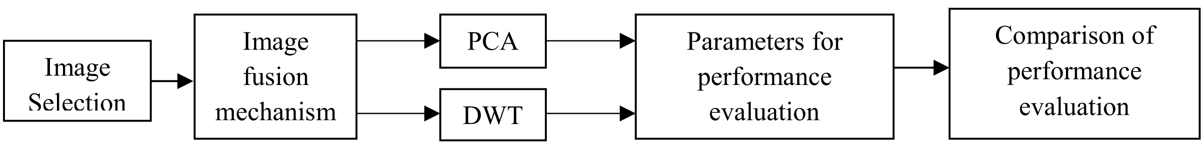

Figure D Block diagram of system design

Figure D shows the block diagram of the system design. The images obtained from the different sources have spatial dependency but due to their different spectral quality, they also exhibit disparity in information content. The information contained in panchromatic images depends on the multispectral reflectivity of the target illuminated by sun

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light. SAR image intensities depend on the characteristics of the illuminated surface target as well as on the signal itself. The fusion of this disparate data contributes to the understanding of the objects observed. For many applications, images of the same location are obtained at different periods of times. This provides us with a large volume of images with different temporal, spectral and spatial resolution

At sub-feature level, many fusion techniques have been developed and are currently in use. In general, fusion techniques may be classified in either of the following categories as Colour based techniques and Statistical/Numerical techniques. Colour based techniques are important because the colour represent the band of frequencies reflected from the imaging location. This provides a human vision perception to the problem. Colour based techniques include transformations such as IHS and HSV.

Statistical approaches are developed on the basis of channel statistics including correlation and filters. Numerical methods follow arithmetic operations such as image differencing and ratios. Sophisticated approaches may be a combination of statistical and numerical methods such as wavelets in multi-resolution environment.

Some standard algorithms for the fusion of satellite images can be described shortly as RGB to HIS, Principal Component Analysis (PCA)-based and Discrete Wavelet Transform (DWT)-based a number of statistical evaluation methods are used to measure after-fusion colour fidelity. The most commonly used measures selected for the study to compare the performance of imge fusion methods are introduced in the following sections.Performance evaluation of system can be analysed using various parameters.

- Deviation Index, RMSE
- Spectral Angle,
- Correlation Index,

V. ANALYSIS OF IMAGE FUSION

For many applications, images of the same location are obtained at different periods of times. This provides us with a large volume of images with different temporal, spectral and spatial resolution. Image fusion is usually performed on following sets:

A. Panchromatic and Multispectral Data: Low-spatial-resolution multispectral images are fused with high resolution panchromatic data. The high resolution of the panchromatic images is preserved along with the information content from the multispectral data.

B. Panchromatic and SAR Data: panchromatic and SAR are usually able to provide complementary data due to their different nature of signal source. This disparity in data is exploited extensively to obtain meaningful maps for different applications such as topographical surveys, vegetation monitoring etc.

Fusion of images is a process of identifying useful information content and combining them efficiently to make the final image more meaningful for a particular application. Depending on the level at which the classification of useful data is done, images may be fused at the following levels:

- Signal level
- Pixel level
- Feature level
- Decision level

A. Techniques of fusion

At sub-feature level, many fusion techniques have been developed and are currently in use. In general, fusion techniques may be classified in either of the following categories

1. Colour based techniques
2. Statistical/Numerical techniques

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B. Standard Methods

Some standard algorithms for the fusion of satellite images can be described shortly as follows:

- RGB to IHS
- Principal Component Analysis (PCA)-based
- Discrete Wavelet Transform (DWT)-based

C. IHS colour model

IHS method consists on transforming the R, G and B bands of the multispectral image into IHS components, replacing the intensity component by the panchromatic image, and performing the inverse transformation to obtain a high spatial resolution multispectral image.

Although the IHS method has been widely used, the method cannot decompose an image into different frequencies in frequency space such as higher or lower frequency. Hence the IHS method cannot be used to enhance certain image characteristics besides, the color distortion of IHS technique is often significant. To reduce the color distortion, the PAN image is matched to the intensity component before the replacement or the hue and saturation components are stretching before the reverse transform.

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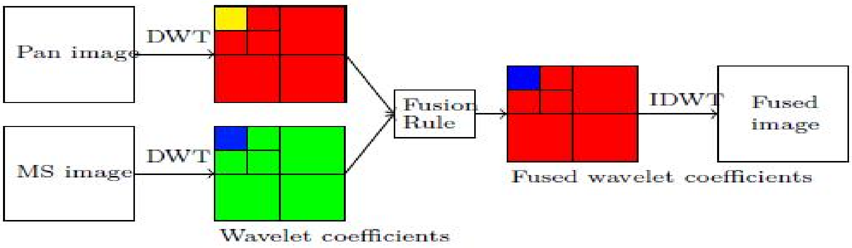
F. Wavelet Transform (WT)

Figure 2 shows Wavelet diagram .In the fusion methods based on wavelet transform, the images are decomposed into pyramid domain, in which coefficients are selected to be fused. The two source images are first decomposed using wavelet transform. Wavelet coefficients from MS approximation subband and PAN detail subbands are then combined together, and the fused image is reconstructed by performing the inverse wavelet transform. Since the distribution of coefficients in the detail subbands have mean zero, the fusion result does not change the radiometry of the original

Multi spectral image. The simplest method is based on the selection of the higher value coefficients, but various other methods have been proposed in the literature.



Wavelet diagram

G Performance evaluation

A number of statistical evaluation methods are used to measure after-fusion colour fidelity. The most commonly used measures selected for the study to compare the performance of image fusion methods are introduced in the following sections. Performance evaluation of system can be analysed using various parameters.

- Deviation Index, RMSE
- Spectral Angle,
- Correlation Index,
- ERGAS and Universal Quality Index

Root Mean Squared Error (RMSE)

The root mean squared error (RMSE) displays spectral distortion of the fused band when compared with the original low spatial resolution data. It is computed by the difference of the standard deviation and the mean of the fused and the original image. The best possible value is again 0.

$$\mathrm{RMSE} = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I_r(i,j) - I_f(i,j)\right)^2}$$

In the above equation, M and N are matrix sizes for the reference and fused images, respectively.

Relative Global Dimensional Synthesis Error (ERGAS)

The formula for Relative Global Dimensional Synthesis

$$\mathrm{ERGAS} = 100\frac{h}{\ell}\sqrt{\frac{1}{n}\sum_{i=1}^{n}\frac{\mathrm{RMSE}_i^2}{\mathrm{MR}_i^2}}$$

where MRi is the mean radiance of the ith MS band, *h* is the spatial resolution of the high resolution image, l is the spatial resolution of the low resolution image. ERGAS offers a global depiction of the quality of radiometric distortion of the fused product. The lower the value of the RMSE index and the ERGAS index, the higher the spectral quality of the fused images.

Universal Image Quality Index (Q-average)

This parameters models any distortion as a combination of three different factors: loss of correlation, luminance distortion, and contrast distortion

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

Existing Method

There are many methods for fusion of images either in gray scale or in colour space, but multi resolution and multi domain images fusion is unclear .They all experience a trade-off between the final spatial and spectral resolutions and there is no method which is clearly the best overall and there is also no standard way to judge the fusion results.

Different techniques to fuse a set of multispectral low-resolution images with a more highly resolved panchromatic image of the same scene were presented. As a result a set of synthetic bands is obtained that combines the spectral and spatial data of the original imagery.

To overcome the need for an auxiliary, more highly resolved image a direct method for combining multispectral remote images to obtain a higher spatial resolution has been described. The additional information is retrieved by using sub-pixel displacement between the distinct spectral bands. The new gained synthetic band is used to sharpen the multispectral band and can be used for any of the described techniques.

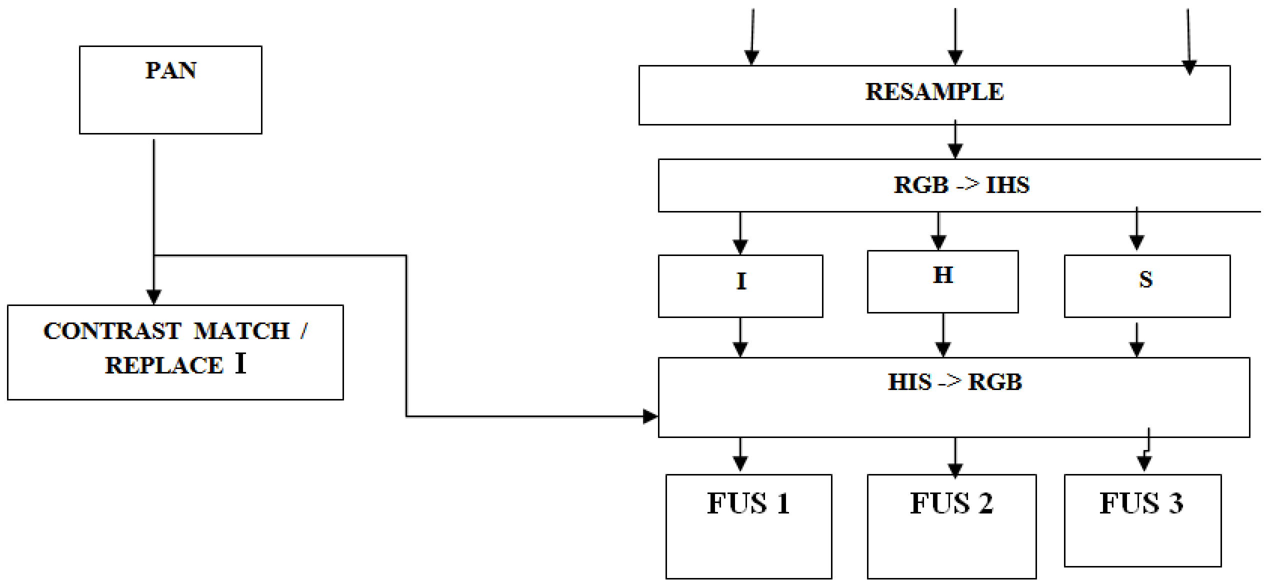
Proposed Method

In this project work a novel method based on transform domain technique is proposed to increase resolution of Multispectral images using Discrete Wavelet Transform and performance evaluation of proposed system is correlated with statistical methods like Principle component analysis

VI. DIFFERENT TYPES OF IMAGE FUSION

A. HIS colour model

This method consists on transforming the R,G and B bands of the multispectral image into IHS components, replacing the intensity component by the panchromatic image, and performing the inverse transformation to obtain a high spatial resolution multispectral image. Figure 3 shows the block of IHS fusion method. Even though the IHS method has been widely used, the method cannot decompose an image into different frequencies in frequency space such as higher or lower frequency. Hence the IHS method cannot be used to enhance certain image characteristics Besides, the color distortion of IHS technique is often significant. To reduce the color distortion, the PAN image is matched to the intensity component before the replacement or the hue and saturation components are stretching before the reverse transform.



B. Principal Components Analysis (PCA)

The Figure shows the PCA method of fusion. PCA is a general statistical technique that transforms multivariate data with correlated variables into one with uncorrelated variables. These new variables are obtained as linear combinations

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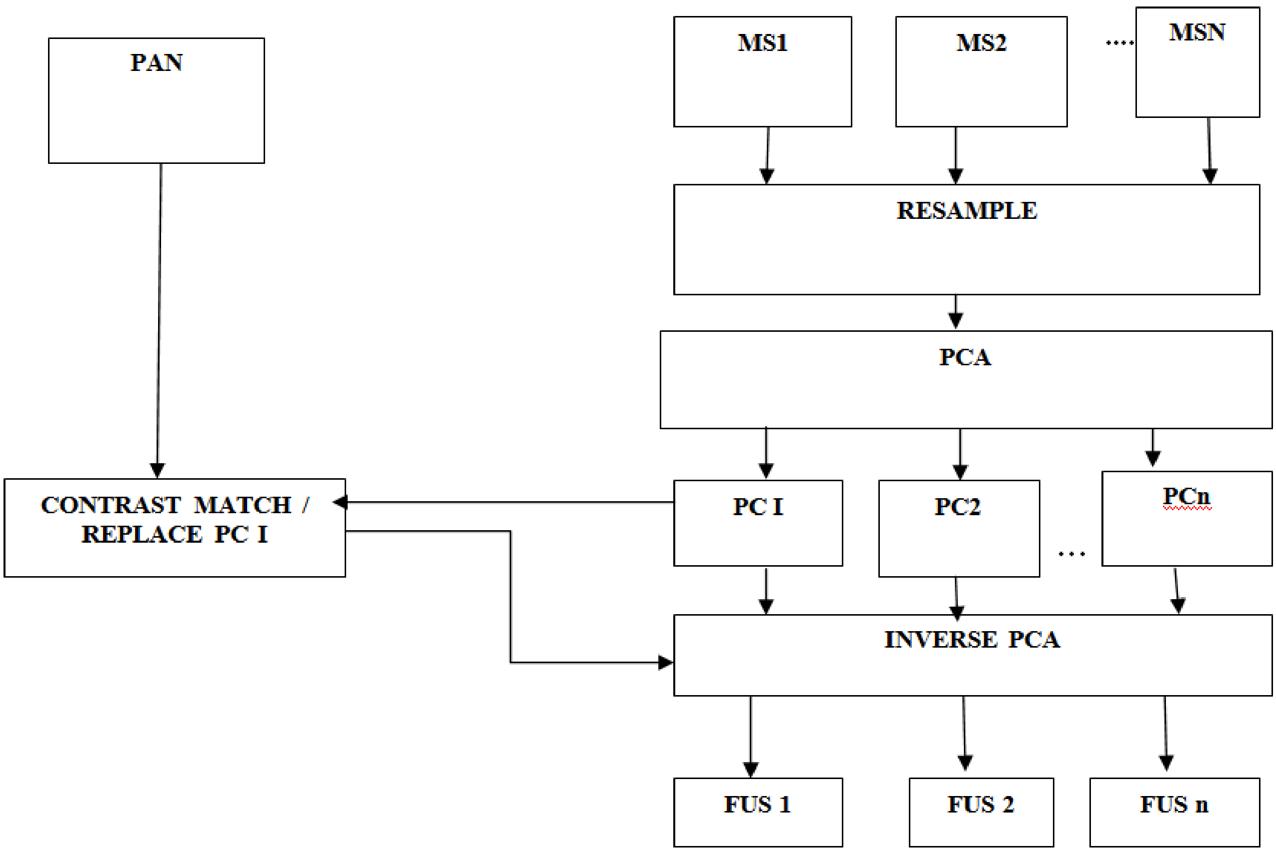
of the original variables. PCA has been widely used in image encoding, image data compression, image enhancement and image fusion. In the fusion process, PCA method generates uncorrelated images (PC1, PC2…PCn, where n isthe number of input multispectral bands). The first principal component (PC1) is replaced with the panchromatic band, which has higher spatial resolution than the multispectral images. Afterwards, the inverse PCA transformation is applied to obtain the image in the RGB color model. In PCA image fusion, dominant spatial information and weak color information is often a Problem. The first principal component, which contains maximum variance, is replaced by PAN image. Such replacement maximizes the effect of panchromatic image in the fused product. One solution could be stretching the principal component to give a spherical distribution.

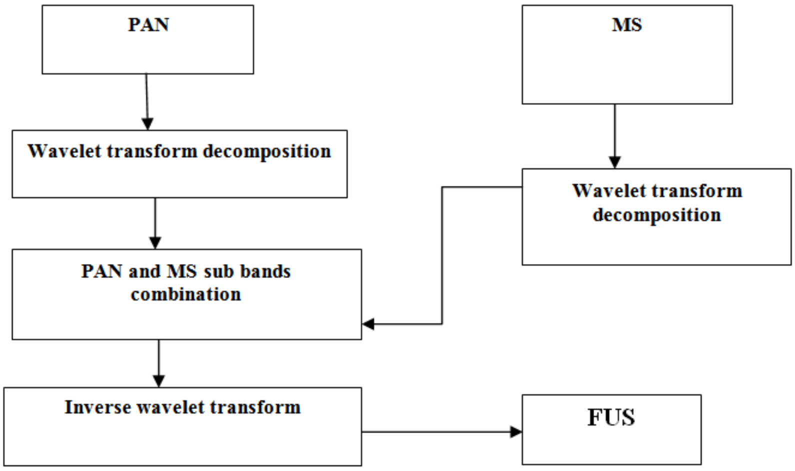


C. Wavelet Transform (WT)

Figure 4 shows Block scheme of the WT fusion method In the fusion methods based on wavelet transform, the images are decomposed into pyramid domain, in which coefficients are selected to be fused. The two source images are first decomposed using wavelet transform. Wavelet coefficients from MS approximation sub band and PAN detail sub bands are then combined together, and the fused image is reconstructed by performing the inverse wavelet transform. Since the distribution of coefficients in the detail sub bands have mean zero, the fusion result does not change the radiometry of the original multispectral image. The simplest method is based on the selection of the higher value coefficients, but various other methods have been proposed in the literature.

The schemes used to decompose the images are based on decimated and un decimated algorithms. In the decimated algorithm, the signal is down-sampled after each level of transformation. In the case of a two-dimensional image, down-sampling is performed by keeping one out of every two rows and columns, making the transformed image one quarter of the original size and half the original resolution. In the lower level of decomposition, four images are produced, one approximation image and three detail images. The decimated algorithm is not shift-invariant, which means that it is sensitive to shifts of the input image. The decimation process also has a negative impact on the linear continuity of spatial features that do not have a horizontal or vertical orientation. These two factors tend to introduce artifacts when the algorithm is used in applications such as image fusion.

On the other hand, the un decimated algorithm addresses the issue of shift-invariance. It does so by suppressing the down-sampling step of the decimated algorithm and instead up sampling the filters by inserting zeros between the filter coefficients. The un decimated algorithm is redundant, meaning some detail information may be retained in adjacent levels of transformation. It also requires more space to store the results of each level of transformation and, although it is shift-invariant, it does not resolve the problem of feature orientation .



Block scheme of the WT fusion method

VII. IMAGE FUSION TECHNIQUES AND MEASUREMENT FOR IMAGE QUALITY

A. Fusion Technique

It focuses verification effort on the unit of software design (module). Using the unit test plans, prepared in the design phase of the system development as a guide, important control paths are tested to uncover errors within the boundary of the modules. The interfaces of each of the module were tested to ensure proper flow of the information into and out of the modules under consideration. Boundary conditions were checked. All independent paths were exercised to ensure that all statements in the module are executed at least once and all error-handling paths were tested. Each unit was thoroughly tested to check if it might fall in any possible situation.

B. Functional testing

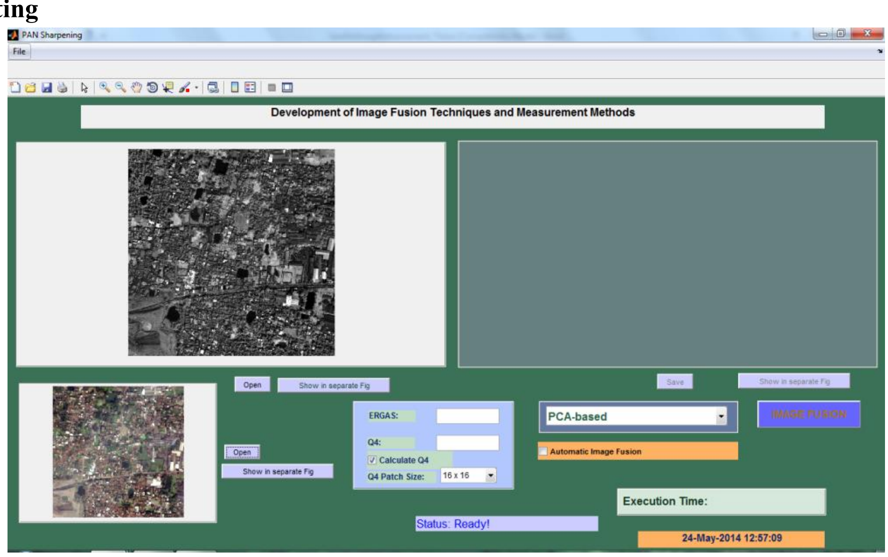


Figure 5-Image enhancement working GUI design

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Functional testing is a type of black box testing that bases its test cases on the specifications of the software component under test. Functions are tested by feeding them input and examining the output, and internal program structure is rarely considered (Not like in white-box testing). After the integration testing, the software was completely assembled as a package; interfacing errors have been uncovered and corrected the final series of software tests, validation tests begin. Validation test succeeds when the software functions in a manner that can be reasonably expected by the customer. Here the system was tested against system requirement specification. System testing was actually a series of different tests whose primary purpose was to fully exercise the computer-based system. Although each test has a different purpose all work to verify that all system elements have been properly integrated and perform allocated functions

Figure 5 shows working GUI design. The above figure has two loaded input images . one is multispectral and another is panchromatic. These two images are used for image fusion.

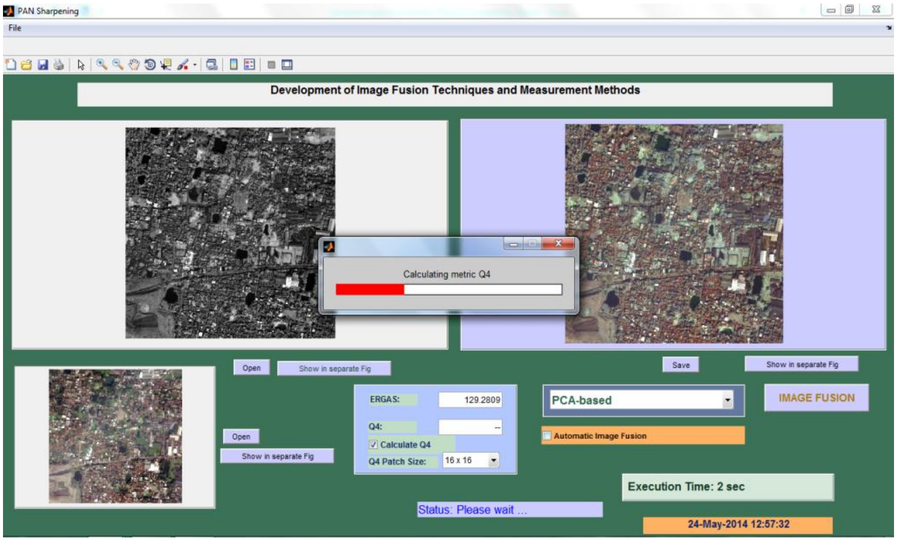

Figure 6-Image enhancement Working Environment

Figure 6 shows working environment of GUI. This layout shows the fused output image which is combination of both pancromatic and multispectral image. This figure also shows the calculation of parameters which includes ERGAS and Q4. The algorithm used here is PCA based.

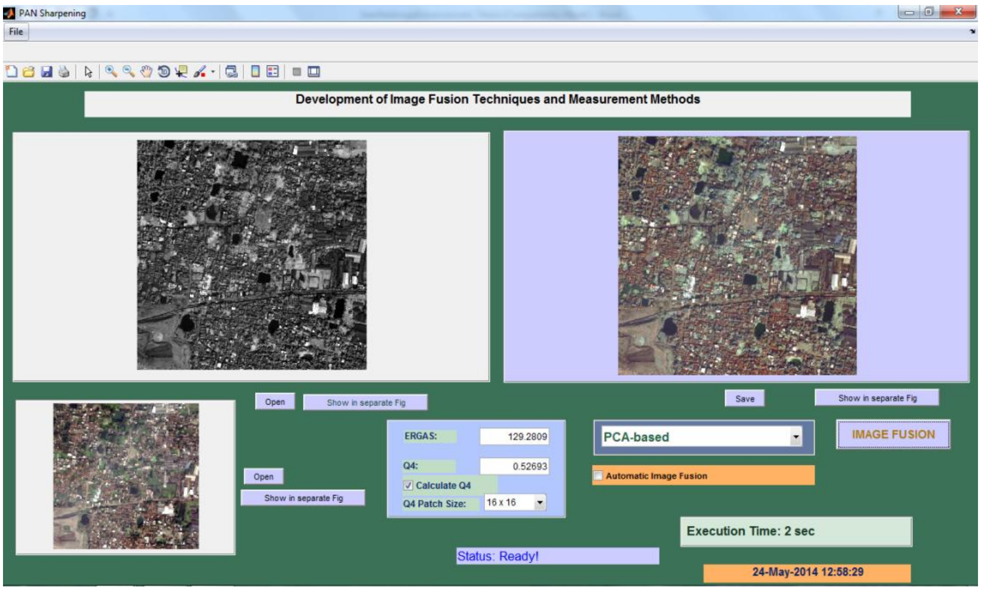

Figure 7- Image enhancement Resultant Output using PCA method

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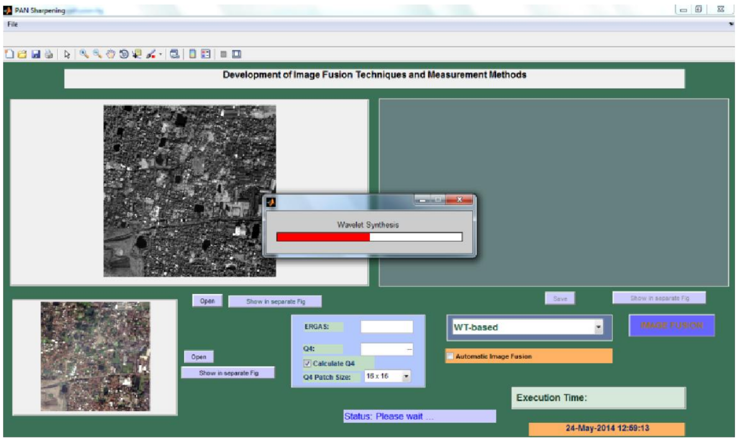

Figure 8 Image enhancement Wavelet Transform Working Environement

Figure 8 shows Image enhancement Wavelet Transform Working Environement. This layout shows the fused output image which is combination of both pancromatic and multispectral image. This figure also shows the calculation of parameters which includes ERGAS and Q4. The algorithm used here is WT based.

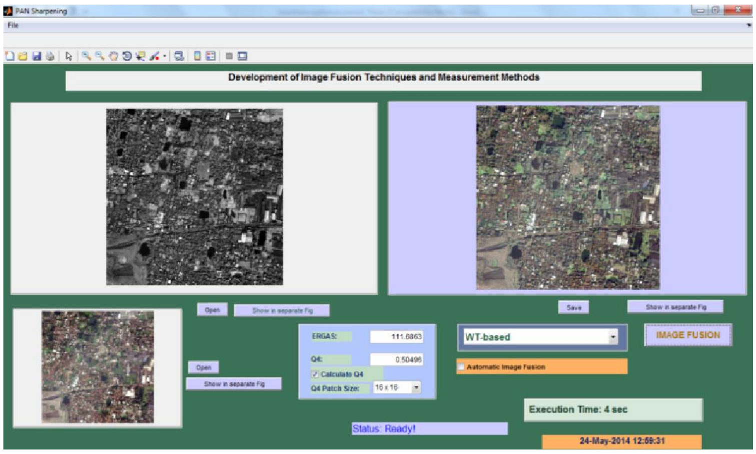

Figure 9- Image enhancement Resultant Wavelet Algorithm

Figure 9 shows Image enhancement Resultant Wavelet Algorithm .This layout shows the fused output image which is combination of both pancromatic and multispectral image.. The algorithm used here is WT based.

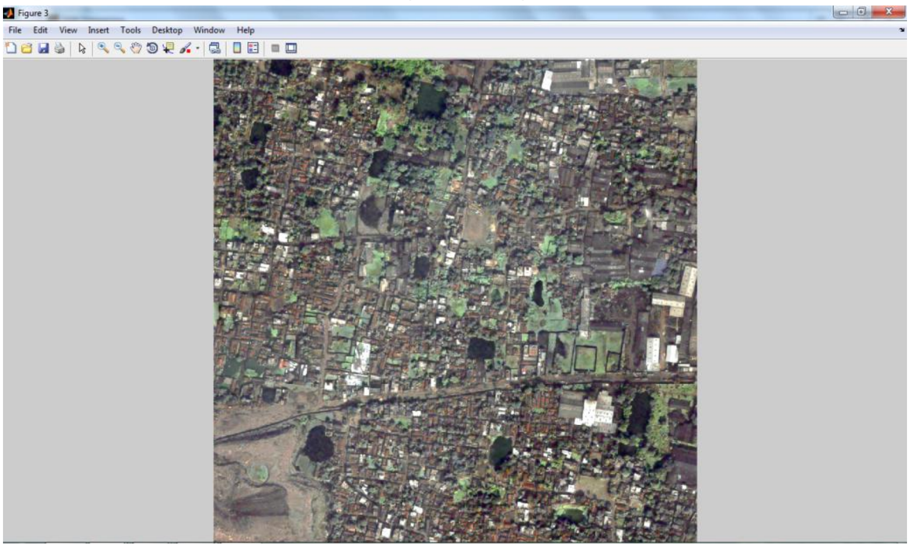

Figure 10-Image enhancement Resultant Wavelet Algorithm

Figure 10 shows Image enhancement Resultant Wavelet Algorithm .this window can be displayed by pressing a button show in separate window. Image can be zoomed in and out in this window.

Parameter	PCA Based Fusion		WT Based Fusion	
ERGAS	129.2809		111.6863	
Q 4	8 by 8	0.43337	8 by 8	0.44466
	16 by 16	0.52693	16 by 16	0.54496
	32 by 32	0.56941	32 by 32	0.59173

Table parameters

In this work, an image fusion algorithm based on wavelet transform is proposed. In the proposed scheme, the images to be processed are decomposed into sub-images with the same resolution at same levels and different resolution at different levels and then the information fusion is performed using high-frequency sub-images under the Multi-resolution image fusion scheme based on wavelets produces better fused image than that by the MS or WA schemes. The use of both gradient and relative smoothness criterion ensures two fold effects:

The gradient criterion ensures that edges in the images are included in the fused algorithm.

The relative smoothness criterion ensures that the areas of uniform intensities are incorporated in the fused image thus; the effect of noise is minimized.

VII. CONCLUSION

Finally, from the above analysis and comparison, we can conclude that Modified IHS algorithm can preserve the spectral characteristics of the source multispectral image as well as the high spatial resolution characteristics of the source panchromatic image and suited for fusion of IRS P5 and P6 images. In PC and Standard IHS image fusion, dominant spatial information and weak color information is an often problem, Therefore are suited for visual interpretation, image mapping, and photogrammetric purposes.

wavelet is the best method in retaining spectral property of the original image among the five used methods at the cost of low spatial information, Therefore are suited for digital classification purposes

Future Enhancement

The work performed does hold scope for further advancements as a lot of research is happening in the field.

The following are some proposed practical advancements possible in the project:

- Multi Wavelets based image fusion can be performed to achieve a better image fusion quality. The efficiency of multi wavelets over the usual DWT methods in fusing images involved in remote sensing. The same can be applied in this project too and can be verified based on the image quality metrics developed.
- The image fusion quality has been assessed based on optical image sets with respect to a a perfect image. The efficiency of the fusion can be better assessed if the same could be performed on many more. multivariate images. The same could not be done due to lack of such set of test sample multivariate images
- A learning algorithm like neural networks and more specifically Support Vector Machine could be devised in assigning weightage to the image quality metrics so as to assess them. A more extensive number of image sets could be considered initiating a learning process using SVM, based on which the metrics could be provided with weighted ranks. This would again require more set of sample images.
- Image Registration has not been incorporated in the work. Image Registration / Image Alignment will certainly enhance the efficiency of the project as vast set of even unregistered images can be considered as set of input images. It would also help in possibility of more set of sample test/perfect images made available for assessing the image fusion algorithms.
- The ImFus Toolkit now looks into considering only two input images to be fused. An option to load and fuse more than two images at the same time can also be easily incorporated into the project. An option could be provided to the user on to select the number of input images available

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