

RADAR Image Fusion Using Wavelet Transform

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Abstract—RADAR Images are strongly preferred for analysis of geospatial information about earth surface to assess environmental conditions radar images are captured by different remote sensors and that images are combined together to get complementary information.

To collect radar images SAR(Synthetic Aperture Radar) sensors are used which are active sensors and can gather information during day and night without affecting weather conditions.

We have discussed DCT and DWT image fusion methods which gives us more informative fused image simultaneously we have checked performance parameters among these two methods to get superior method from these two techniques.

Keywords—DCT, DWT, RADAR, Synthetic Aperture Radar

I. INTRODUCTION

Image Fusion is one of the major research fields in image processing. Image Fusion is a process of combining the relevant information from a set of images, into a single image, wherein the resultant fused image will be more informative and complete than any of the input images. Image fusion process can be defined as the integration of information from a number of registered images without the introduction of distortion. It is often not possible to get an image that contains all relevant objects in focus. One way to overcome this problem is image fusion, in which one can acquire a series of pictures with different focus settings and fuse them to produce an image with extended depth of field. Image fusion techniques can improve the quality and increase the application of these data. This project report discusses the two categories of image fusion algorithms DCT based algorithm and the basic DWT algorithm. It gives a literature review on some of the existing image fusion techniques for image fusion like, primitive fusion (Averaging Method, Select Maximum, and Select Minimum), Discrete Wavelet transform based fusion, Principal component analysis (PCA) based fusion etc.

Image fusion is the process of combining information from two or more images of a scene into a single composite

image that is more informative and is more suitable for visual perception or computer processing.

The objective in image fusion is to reduce uncertainty and minimize redundancy in the output while maximizing relevant information particular to an application or task. Given the same set of input images, different fused images may be created depending on the specific application and what is considered relevant information.

There are several benefits in using image fusion: wider spatial and temporal coverage, decreased uncertainty, improved reliability, and increased robustness of system performance.

In applications of digital cameras, when a lens focuses on a subject at a certain distance, all subjects at that distance are sharply focused. Subjects not at the same distance are out of focus and theoretically are not sharp. It is often not possible to get an image that contains all relevant objects in focus. One way to overcome this problem is image fusion, in which one can acquire a series of pictures with different focus settings and fuse them to produce an image with extended depth of field. During the fusion process, all the important visual information found in the input images must be transferred into the fused image without introduction of artifacts. In addition, the fusion algorithm should be reliable and robust to imperfections such as noise or misregistration. Image fusion is a branch of data fusion where data appear in the form of arrays of numbers representing brightness, colour, temperature, distance, and other scene properties. Such data can be two-dimensional (still images), three-dimensional (volumetric images or video sequences in the form of spatial-temporal volumes), or of higher dimensions. In recent years, multivariate imaging techniques have become an important source of information to aid diagnosis in many medical fields. Early work in image fusion can be traced back to the mid-eighties. Jingling M. (2012) "Wavelet Fusion on Ratio Images for change Detection in SAR Images" present a novel method based on wavelet fusion for change detection in synthetic aperture radar (SAR) images. The proposed approach is applied to generate the difference image (DI) by using complementary information from mean-ratio and log-ratio images. To restrain the background (unchanged

areas) information and enhance the information of changed regions in the fused DI, fusion rules based on weight averaging and minimum standard deviation are chosen to fuse the wavelet coefficients for low and high-frequency bands, respectively. Experiments on real SAR images confirm that the proposed approach does better than the mean-ratio, log-ratio, and Rayleigh-distribution-ratio operators.

II. LITERATURE REVIEW

Burt (1984) [2] "The pyramid as a structure for efficient computation" was one of the first to report the use of Laplacian pyramid techniques in binocular image fusion and later on Burt and Adelson (1987) [3] "Depth-of-Focus Imaging Process Method" later introduced a new approach to image fusion based on hierarchical image decomposition at about the same time Adelson disclosed the use of a Laplacian technique in construction of an image with an extended depth of field from a set of images taken with a fixed camera but with different focal lengths. Later Toet (1989) [4] "Image fusion by a ratio of low pass pyramid" used different pyramid schemes in image fusion which were mainly applied to fuse visible and IR images for surveillance purposes. Some other early image fusion work are due to Lillquist (1988) [5] "Composite visible/thermal-infrared imaging apparatus" disclosing an apparatus for composite visible/thermal infrared imaging, Ajjimarang (1988) [6] "Neural network model for fusion of visible and infrared sensor outputs" suggesting the use of neural networks in fusion of visible and infrared images, Nandha kumar and Aggarwal (1988) [7] "Integrated analysis of thermal and visual images for scene interpretation" providing an integrated analysis of thermal and visual images for scene interpretation, and Rogers et al. (1989) [8] "Multisensor fusion of RADAR and passive infrared imagery for target segmentation" describing fusion of RADAR and passive infrared images for target segmentation. Use of the discrete wavelet transform (DWT) in image fusion was almost simultaneously proposed by Li and Chipman (1995) [9] "Wavelets and image fusion" at about the same time Koren (1995) [10] "Image fusion using steerable dyadic wavelet" described a steerable dyadic wavelet trans-form for image fusion and also around the same time Waxman and colleagues developed a computational image fusion methodology based on biological models of colour vision and used opponent processing to fuse visible and infrared images. The need to combine visual and range data in robot navigation and to merge images captured at different locations and modalities for target localization and tracking

in defense applications prompted further research in image fusion

III. SYSTEM DEVELOPMENT

a) Basic Image Fusion

An illustration of an image fusion system is shown in Figure 1. The sensor shown could be a visible-band sensor such as a digital camera. This sensor captures the real world as a sequence of images. The sequence is then fused in one single image and used either by a human operator or by a computer to do some task. For example in object detection, a human operator searches the scene to detect objects such intruders in a security area.

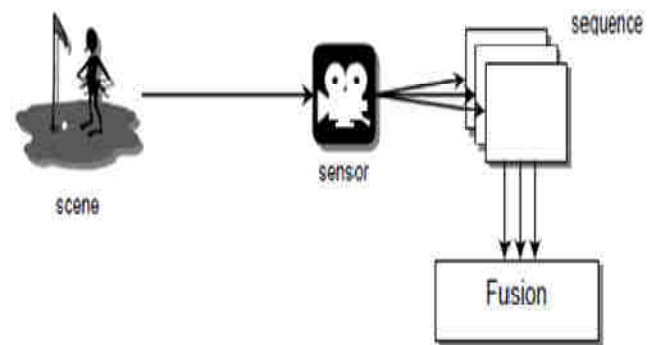


Fig. 1: Basic Image Fusion System

This kind of systems has some limitations due to the capability of the imaging sensor that is being used. The conditions under which the system can operate, the dynamic range, resolution, etc. are all limited by the capability of the sensor. For example, a visible-band sensor such as the digital camera is appropriate for a brightly illuminated environment such as daylight scenes but is not suitable for poorly illuminated situations found during night, or under adverse conditions such as in fog or rain.

The image fusion techniques mainly perform a very basic operation like pixel selection, addition, subtraction or averaging. These methods are not always effective but are at times critical based on the kind of image under consideration. Following are some of the image fusion techniques studied and developed as part of the project.

b) Average Method

As the concept of information fusion arose from the idea of averaging the available information. Image Fusion also saw a similar background, wherein the most simplistic was to fuse a set of input image was to average the pixel intensities of the corresponding pixels. The fused image produced by this method projects both the good and the bad information from the input images. Due to the averaging operation, both the good and the bad information are minimized arriving at an averaged image. Thus the

algorithm does not actually fuse the images perfectly. The algorithm, being the simplest one, can be put in one step as the following:

1) Calculate the average intensity value of each corresponding pixel of the pair of input images

c) Select Maximum Method

The Selection method is also one of the trivial methods of image fusion. But unlike averaging method, instead of averaging every corresponding pixel, a selection process is performed here. The criterion of selection is self-explained by the name of the method. Of every corresponding pixel of the input images, the pixel with maximum intensity is selected and is put in as the resultant pixel of the fused image. Thus, effectively, every pixel of the fused image will be the pixel with maximum intensity of the corresponding position pixels in the input image. One advantage of this method over averaging method is that there is no compromise made over the good information available in the input images. A straight forward selection of the better pixel intensity is made here. But of course, it is combined with the disadvantage that higher pixel intensity does not always mean better information. It depends on the type of image under consideration. Thus, you either take the whole of the information or totally avoid the same. The stepwise description of the algorithm is as the following:

- 1) Compare the intensity value of the corresponding pixels of the input pair of images.
- 2) Generate the selection matrix based on the comparison performed in 1, assigning value 1 for condition being true and 0 otherwise
- 3) Multiply the corresponding value in the selection matrix with first image matrix
- 4) Multiply the corresponding value in the negated selection matrix with second image matrix.
- 5) Resultant image matrix is calculated by adding the matrices calculated in 3 and 4

d) Select Minimum Method

The minimum selecting method, being yet another trivial image fusion method, is very similar to the Maximum Selection method; except for, here, the selection criteria differs as the pixel with minimum density is picked up. Thus, for every pixel position, the pixel of the fused image will be the pixel of the corresponding position from the input set of images having the least pixel intensity value. Similar to the Maximum Selection method, this method to either completely considers the information from an input image or discards it fully. No averaging or any operation of the like is performed here. The quality of the fusion is specific to the type of image we are dealing with. In certain cases, say, images with dark shades would generate a good

fusion image with this method. The stepwise description of the algorithm is discussed below.

- 1) Compare the intensity value of the corresponding pixels of the input pair of images.
- 2) Generate the selection matrix based on the comparison performed in 1, assigning value 0 for condition being true and 1 otherwise.
- 3) Multiply the corresponding value in the selection matrix with first image matrix
- 4) Multiply the corresponding value in the negated selection matrix with second image matrix.
- 5) Resultant image matrix is calculated by adding the matrices calculated in 3 and 4.

e) Fusion Techniques

Data fusion techniques combine data from different sources together. The main objective of employing fusion is to produce a fused result that provides the most detailed and reliable information possible. Fusing multiple information sources together also produces a more efficient representation of the data.

There are three categories of data fusion:

- i). Pixel / Data level fusion: It produces a fused image in which information content related with each pixel is concluded from a set of pixels in source images. Fusion at this level can be carried out either in spatial or in frequency domain. However, pixel level fusion may conduct to contrast reduction pixel level fusion is the combination of the raw data from multiple source images into a single image.
- ii). Feature level fusion: Feature level fusion requires the extraction of salient characteristics which are depending on their surroundings such as pixel intensities, edges or textures. These analogous attribute from the input images are fused. This fusion level can be used as a means of creating supplementary amalgamated attributes. The fused image can also be used for classification or detection feature level fusion requires the extraction of different features from source data before features are merged together
- iii). Decision level fusion: Decision level is a superior level of fusion. Input images are processed independently for information mining. The obtained information is then united applying decision rules to emphasize widespread interpretation decision level fusion combines the results from multiple algorithms to yield additional fused decision.

IV. USED METHODOLOGY

Discrete Cosine Transformation.

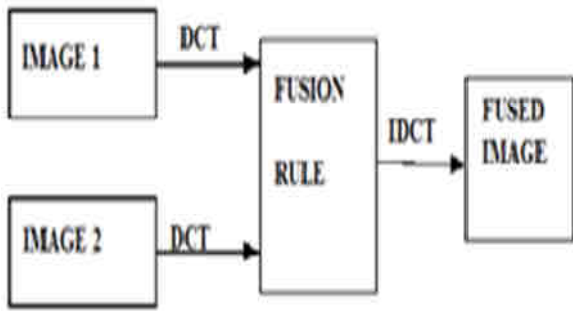


Fig. 2: DCT Operation

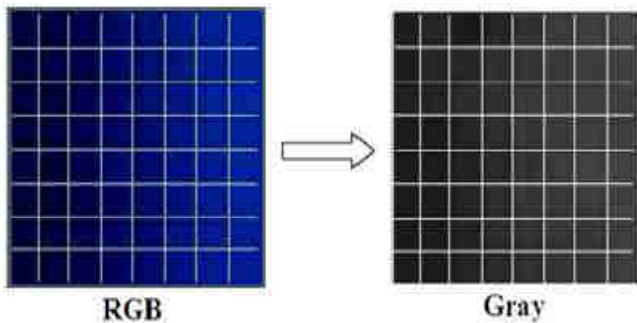


Fig. 3: Colour Image to gray scale image(A)

DCT operation is shown Figure 2. This experiment tries the method of 2-D Discrete Cosine Transformation (DCT) at first. The image should be gray scale before the DCT starts, after the gray scale transformation is completed, just start the process of 2 dimensions Discrete Cosine Transformation (DCT) for each 8*8 blocks. The process of the RGB image transformed to gray scale image is shown in Figure 2 and Figure 3.

According to the Figure 3, the RGB image is divided into blocks with size of 8*8 pixel with blue colour in gradient, the gradient scalar field is show the direction from left (deep blue) to right (light blue). After gray scale, the RGB image should be in gray colour, the gradient scalar field is show the direction from left (black) to right (gray). Figure 4. showed the processing of gray scale, the image is grouped by matrices of red, green and blue, and it converts to one grey matrix. This matrix will be used in next DWT transformation.

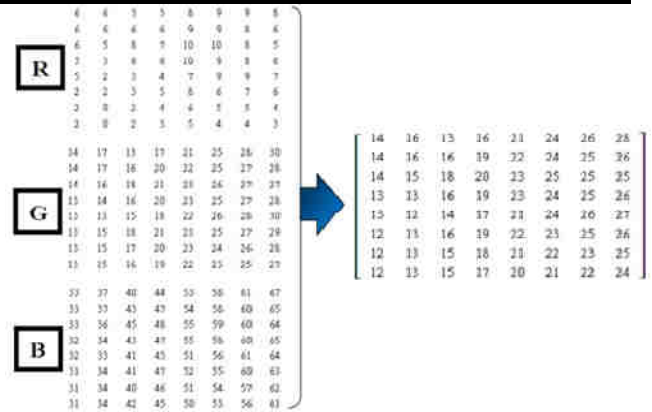


Fig. 4: Colour image to gray scale image(B)

After the matrix of gray scale will process the two dimensional Discrete Cosine Transformation (DCT2), the definition two dimensional of Discrete Cosine Transformation (DCT2) is:

$$c(u, v) = \alpha \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \left[\cos \left(\frac{\pi(2x+1)u}{2N} \right) \cos \left(\frac{\pi(2y+1)v}{2N} \right) \right] \quad (1)$$

The two dimensional Discrete Cosine Transformation (DCT2) is defined that frequency of gray scale blocks convert from spatial domain to frequency domain and gain the result of frequency matrix. Discrete Cosine Transformation (DCT) has the characteristic of energy compact. In the following steps, we will observe the distribution of AC values by STD calculation.

Discrete wavelet Transformation

The discrete wavelet transform [10] is a spatial frequency domain disintegration that presents a bendable multi-resolution analysis of an image. In 1-D, the mean of the wavelet transform is corresponding to the signal as a superposition of wavelets. If a isolated signal is correspond to by f(t) its wavelet decomposition is then

$$f(t) = \sum m, n c_{m,n} \varphi_{m,n}(t) \quad (2)$$

where m and n are integers.

This guarantees that the signal is decomposed into normalized wavelets at octave scales. For an recursive wavelet transform supplementary coefficients a m,n are mandatory at every scale. At each am, n and am-1,n illustrate the approximations of the function 'f' at resolution 2m and at the coarser resolution 2m-1 correspondingly while the coefficients cm ,n illustrate the difference among one approximation and the other. In order to obtain the coefficients cm, n and am, n at each scale and position, a scaling function is needed that is similarly defined to equation (3.3). The convolution of the scaling function with the signal is implemented at each scale through the iterative filtering of the signal with a low pass

FIR filter h_n . The approximation coefficients $a_{m,n}$ at each scale can be obtained using the following recursive relation:

$$a_{m,n} = \sum_k h_{2n-k} a_{m-1} \quad (3)$$

Where the top level $a_{0,n}$ is the sampled signal itself.

In addition, by using a related high pass FIR filter g_n the wavelet coefficients can be obtained by

$$a_{m,n} = \sum_k g_{2n-k} a_{m-1} \quad (4)$$

To renovate the original signal the examination filters can be selected from a bi-orthogonal set which have a correlated set of synthesis filters. These synthesis filters $h(m,n)$ and $g(m,n)$ can be used to absolutely renovate the signal using the renovation formula:

$$a_{m-1}i(f) = \sum_n (h_{2n-1}a_{m,n}(f) + g_{2n-1}c_{m,n}(f)) \quad (5)$$

Equations (4) and (5) are implemented by filtering and subsequent down sampling. Conversely equation (3.4) is implemented by an initial up sampling and a subsequent filtering. A single stage wavelet

A Discrete Wavelet Transform (DWT) is a transform for which the wavelets are discretely sampled.

The DWT of a signal x is calculated by passing it through a series of filters. First the samples are passed through a low pass filter with impulse response g resulting in a convolution of the two.

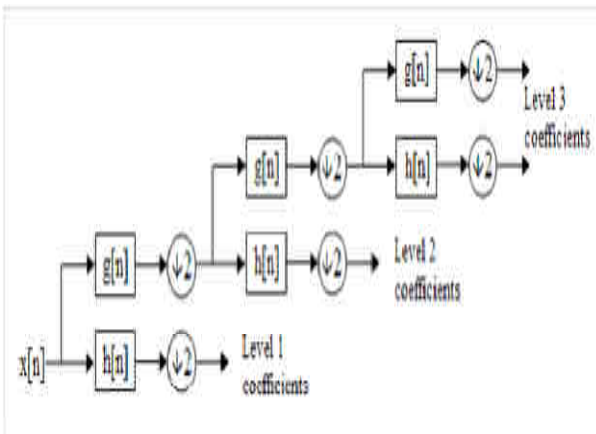


Fig. 5: Three level Filter

At each level in the above diagram the signal is decomposed into low and high frequencies. Due to the decomposition process the input signal must be a multiple of 2^n where n is the number of levels. Before process of Discrete Wavelet Transformation (DWT), the original image should be converted into the gray scale first similarly. After Discrete Wavelet Transform (DWT)

transformation we get four sub bands, which are LL, LH,HL and HH. From the Figure 4, the original image shows in 4×4 blocks and the processing and converting are shown in Figure 5. After the DWT, the standard deviation of frequencies in LH, HL and HH Will be calculated in the following steps

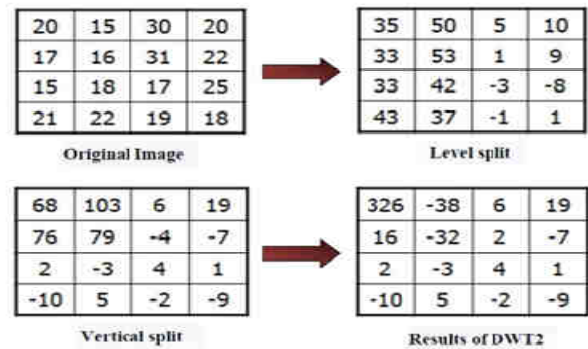


Fig. 6: Result of DWT

Flowchart of DCT Image Fusion

As shown in flow chart, the function developed to perform the image fusion, has four basic blocks:

- Block A: Images size checking.
- Block B: RGB to Gray Conversion.
- Block C: DCT domain fusion.
- Block D: Inverse DCT transform

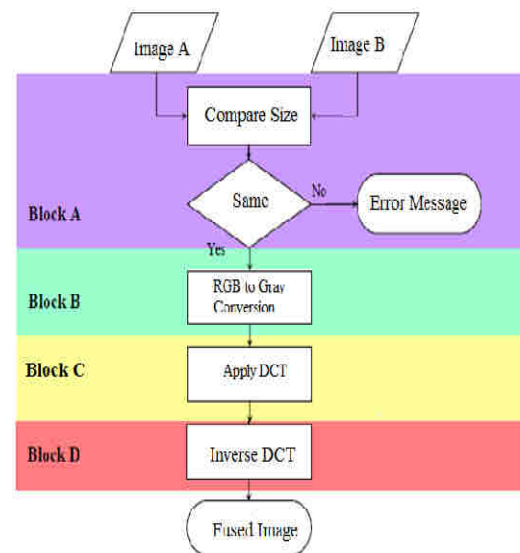


Fig. 7: Flowchart of DCT

Flowchart of DWT Image Fusion

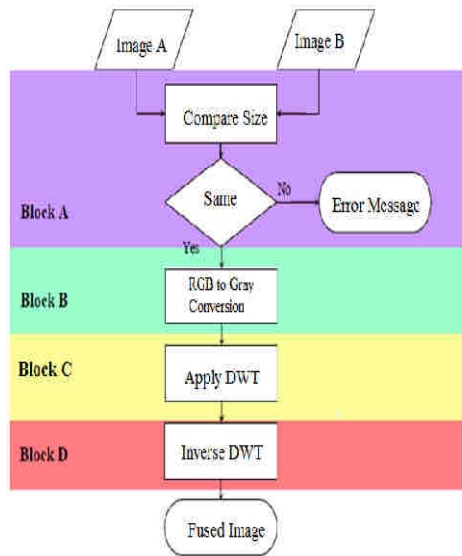


Fig. 8: Flowchart of DWT

As shown in flow chart, the function developed to perform the image fusion has 4 basic blocks:

- Block A: images size checking.
- Block B: RGB to Gray Conversion.
- Block C: DWT domain fusion.
- Block D: inverse DWT transform

V. PERFORMANCE ANALYSIS

i. Mean square error (MSE)

$$MSE = \frac{1}{mn} \sum_{i=1}^m \sum_{j=1}^n (A_{ij} - B_{ij})^2 \quad (6)$$

Where,

m is the height of the Image implying the number or pixel rows,

n is the width of the image, implying the number of pixel columns,

A_{ij} being the pixel density values of the perfect image,

B_{ij} being the pixel density values of the fused image.

Mean square error is one of the most commonly used error projection method where, the error value is the value difference between the actual data and the resultant data. The mean of the square of this error provides the error or the actual difference between the expected/ideal results to the obtained or calculated result.

Here, the calculation is performed at pixel level. A total of m*n pixels are to be considered. A_{ij} will be the pixel density value of the perfect image and B_{ij} being that of the fused image. The difference between the pixel density of the perfect image and the fused image is squared and the mean of the same is the considered error. MSE value will be 0 if both the images are identical.

ii. Peak Signal to Noise Ratio (PSNR):

$$PSNR = 10 \log_{10} \left(\frac{(peak)^2}{MSE} \right) \quad (7)$$

PSNR is defined as in the above expression. This basically projects the ratio of the highest possible value of the data to the error obtained in the data.

In our case, at pixel level, the highest possible value is 255. i.e. in a 8 bit gray scale image, the maximum possible value is having every bit as 1 ! 11111111; which is equal to 255. The error between the fused image and the perfect image is calculated as the Mean Square Error and the ratio value if obtained. If both the fused and the perfect images are identical, then the MSE value would be 0. In that case, the PSNR value will remain undefined.

iii. Normalized Absolute Error (NAE)

$$NAE = \frac{\sum_{i=1}^m \sum_{j=1}^n (A_{ij} - B_{ij})}{\sum_{i=1}^m \sum_{j=1}^n (A_{ij})} \quad (9)$$

Where, m is the height of the Image implying the number or pixel rows n is the width of the image, implying the number of pixel columns.

A_(i,j) being the pixel density values of the perfect image.

B_(i,j) being the pixel density values of the fused image.

This is a metric where the error value is normalized with respect to the expected or the perfect data. That is, the net sum ratio between the error values and the perfect values is calculated. The net sum of the error value which is the difference between the expected values and the actual obtained values is divided by the net sum of the expected values.

In our case, the metric is calculated in the pixel level wherein the net sum of the difference between the perfect image and the corresponding pixel values in the fused image is divided by the net sum of the pixel values in the perfect image. The Normalized Absolute value will be zero (0) if both the fused and the perfect images are identical.

iv. Normalized Cross Correlation (NCC)

$$NCC = \frac{\sum_{i=1}^m \sum_{j=1}^n (A_{ij} - B_{ij})}{\sum_{i=1}^m \sum_{j=1}^n (A_{ij})^2} \quad (10)$$

Where,

m is the height of the Image implying the number or pixel rows

n is the width of the image, implying the number of pixel columns.

A_(i,j) being the pixel density values of the perfect image.

B_(i,j) being the pixel density values of the fused image.

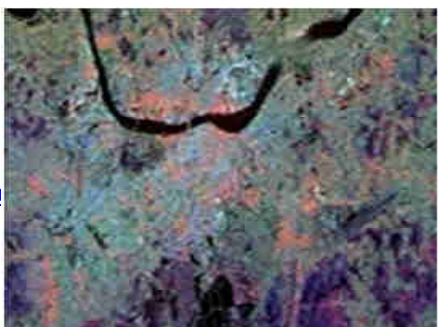
Here a cross correlation is performed between the expected data and the obtained data and normalized with respect to the expected data. This is the ratio value between net sum of the correlated of the expected and obtained data and the expected data. It will be the ratio between the net sum of the multiplied values of the expected and then obtained values and the net sum of the squared expected values.

In our case, the metric is calculated as the ratio between the net sum of the multiplication of the corresponding pixel densities of the perfect and the fused images and the net sum of the squared values of the pixel densities of the perfect images. The Normalized Cross Correlation value would ideally be 1 if the fused and the perfect images are identical.

VI. OBSERVATION AND RESULT

a. Dataset

To evaluate the performance of DCT and DWT for image fusion, Synthetic Aperture Radar image of Kolkata city is considered. A dataset is taken from the website [33] <http://www.jpl.nasa.gov/radar/sircxsar/>. A description of data set used for the experimentation is as follows- This radar image of Kolkata, India, illustrates different urban land use patterns. Kolkata, the largest city in India, is located on the banks of the Hugli River, shown as the thick, dark line in the upper portion of the image. The surrounding area is a at swampy region with a subtropical climate. As a result of this marshy environment, Kolkata is a compact city, concentrated along the fringes of the river. The average elevation is approximately 9 meters (30 feet) above sea level. Kolkata is located 154 kilometers (96 miles) upstream from the Bay of Bengal. Central Kolkata is the light blue and orange area below the river in the centre of the image. The bridge spanning the river at the city center is the Howrah Bridge which links central Kolkata to Howrah. The dark region just below the river and to the left of the city centre is Maidan, a large city park housing numerous cultural and recreational facilities. The international airport is in the lower right of the image. The bridge in the upper right is the Bally Bridge which links the suburbs of Bally and Baranagar. This image is 30 kilometers by 10 kilometers (19 miles by 6 miles) and is cantered at 22.3 degrees north latitude, 88.2 degrees east longitude. North is toward the upper right. The colors are assigned to different radar frequencies and polarizations as follows: red is L-band, horizontally transmitted and received; green is L-band, horizontally transmitted and vertically received; and blue is C-band, horizontally transmitted and vertically received. The image was acquired by the Space borne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) on October 5, 1994, on board the Space Shuttle Endeavour. SIR-C/X-SAR,



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mission of the German, Italian and United States space agencies, is part of NASA's Mission to Planet Earth program.

Space borne Imaging Radar-C and X-Band Synthetic Aperture Radar (SIR-C/X-SAR) is part of NASA's Mission to Planet Earth. The radars illuminate Earth with microwaves allowing detailed observations at any time, regardless of weather or sunlight conditions. SIR-C/X-SAR uses three microwave wavelengths: L-band (24 cm), C-band (6 cm) and X-band (3 cm). The multi-frequency data will be used by the international scientific community to better understand the global environment and how it is changing. The SIR-C/X-SAR data, complemented by aircraft and ground studies, will give scientists clearer insights into those environmental changes which are caused by nature and those changes which are induced by human activity. SIR-C was developed by NASA's Jet Propulsion Laboratory. X-SAR was developed by the Dornier and Alenia Spazio companies for the German space agency,

Fig. 9: Image

Deutsche Agentur fuer Raumfahrt angele genheiten (DARA), and the Italian space agency, Agenzia Spaziale Italiana (ASI), with the Deutsche Forschungsanstalt fuer Luft und Raumfahrt e.v.(DLR), the major partner in science, operations, and data processing of X-SAR.

Here, the input images are pair of images, with one of them being blurred on right hand side upper most corner while another image is blurred on left hand side upper most corner.



Fig.10: Image B

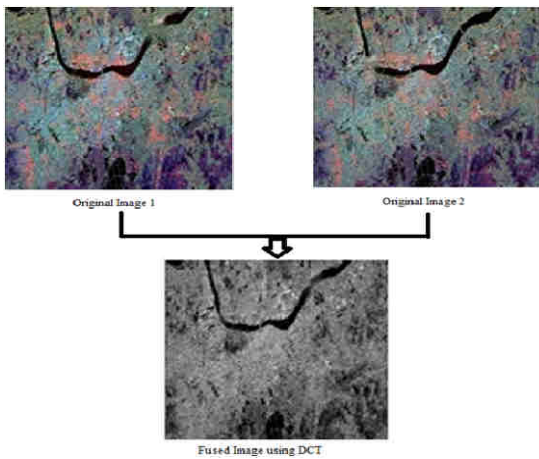


Fig. 11: DCT Image Fusion

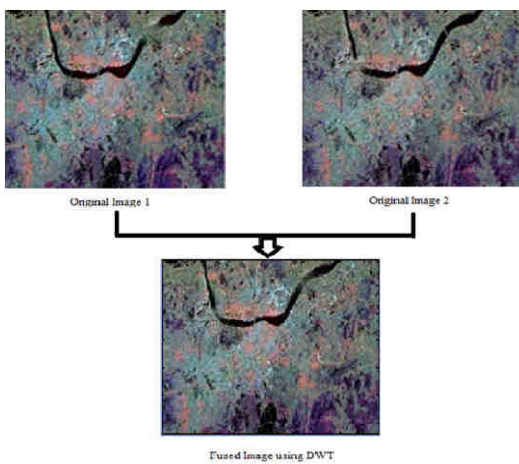


Fig.12: DWT Image Fusion

b. Observations and Results:

Table1. Performance Parameters

Performance Parameters				
Fusion Method	Peak Signal To Noise Ratio(P SNR)	Mean Square Error(MSE)	Normalised Absolute Error (NAE)	Normalised CrossCorelation (NCC)
DCT	18.3991	940.0878	0.49	1.4
DWT	31.1174	50.2736	0.038	0.99

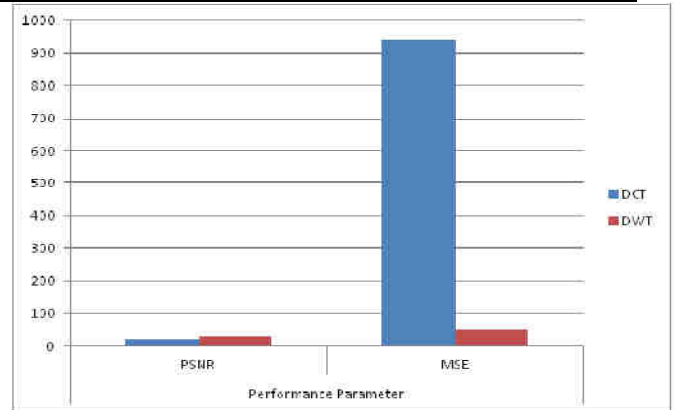


Fig. 13: Performance Parameter(PSNR,MSE)

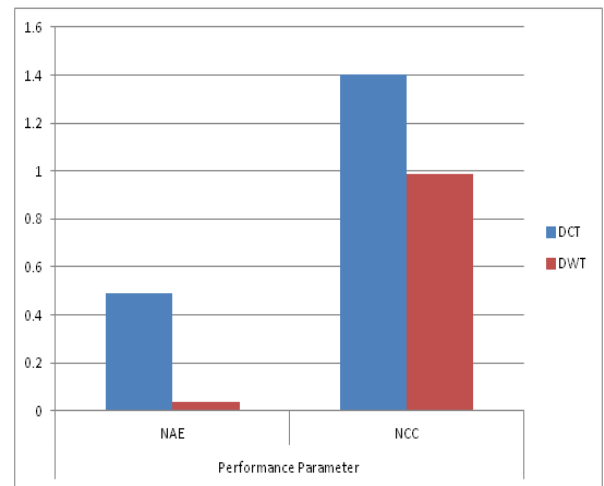


Fig. 14: Performance Parameter (NAE and NCC)

VII. APPLICATIONS

In many applications area, the image fusion plays an important role.

1.Military and civilian surveillance:

Reconnaissance, surveillance and targeting of a selected point as SAR can provide day-and-night imaging, to distinguish terrain features and recognize military staff. It is also used for the non-proliferation of nuclear, chemical and biological weapons

2.On the Ocean:

Detection of sea changes, from man-made illegal or accidental spills, the natural seepage from oil deposits, the detection of ships, the backscattered from the ocean surface to detect wind or current fronts or internal waves. In shallow waters it is able to detect bottom topography, also with the ERS altimeter, the scientists can define the sea bottom due the surface refraction has variations of the surface height, and eddies detection.

If we talk about the wave mode sensor in the ERS SAR satellite, it can provide the scientists of ocean wave direction to make wave forecasting and obtain marine climatology information.

At high latitudes, SAR can detect the ice state, its concentration, thickness, leads detection.

3.Land use change analysis

In forestry and agriculture, SAR images are really important due the wavelength can penetrate the clouds in the most problematic areas, such as the tropics, monitoring the land and its state.

Geological and geomorphological features due the waves can penetrate some vegetation cover and obtain information about the surface covered by it.

To georefer other satellite imagery updating some thematic maps more frequently.

SAR it is also useful to check the aftermath of a flood to assess quicker the damages.

4.Crop stress detection

5.Assessment of deforestation

6.Disaster management (e.g., monitoring of changes during flooding)

7.Ice monitoring

8.Medical diagnosis and treatment

9.Urban planning.

VIII. CONCLUSION

The two image fusion techniques were implemented using MATLAB. The fusion was performed on a pair of input RADAR images. The fused images were verified for their quality based on the image metrics developed and visual perception was compared to assess the credibility of the image metrics. In this project two image fusion techniques based on transform domain, DCT and DWT are used. By the means of the four image metrics developed - PSNR, MSE, NCC and NAE the Discrete wavelet transform (DWT) was assessed as the fusion algorithm producing a fused image of superior quality compared to the discrete cosine transform (DCT).

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