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Review Article

A REVIEW UPON FAST DISCRETE CURVELET TRANSFORMS IN SATELLITE IMAGE PROCESSING

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A B S T R A C T

Image Fusion based on the Fourier, M.IHS, PCA & wavelet transform methods displays rich multispectral details but they are poor when considering to the Spatial Details from the inputs we feed to them from the satellites. Although, Wavelets came more accurate in making the Linear Features of the Image but when coming to the nonlinear discontinuities in the image then the Curvelet Transforms have emerged up into the frame that overcame the problem in the feature representation. Moreover, Image fusion is increasingly its applications in different areas like Satellite Imaging, Remote Sensing, Multi focus Imaging. In our project we are proposing a novel fusion method with the Fast Discrete Curvelet Transforms (FDCT) that increases not only the efficiency of the image but also the feature representation of the Image both in the context of the Linear & Non-Linear Representations. For the experimental study we have considered Low Resolution(LR) Multispectral Image and as well as a High Resolution(HR) Panchromatic Image to generate a High Resolution(HR) Multispectral Image, which is quantitatively compared with Wavelet, PCA, HPF, M.IHS and Grams-Schmidt fusion Methods, which has outperformed spatially the other methods and retains rich multispectral details.

INTRODUCTION

Images are the easiest and most probable method of representing data which seems to be the most easier way to understand. Modern Cameras Capture the information in the same optical manner converted into digital format by Sampling & quantizing it into digital form, since most of the images today are digital in nature. Digital Image Processing often known as DIP is the easiest way of performing various actions upon an Image. Most Probably it performs five fundamental procedure upon the Image namely - Enhancement, Restoration, Analysis, Compression, Synthesis.

Image Fusion is one of the most probable advantage today when it comes to process multiple sensory at a single instant and to analyze the results in a very compact mode. It has a very vivid opportunities in fields like Remote Sensing of data, Satellite Imagery, multi focus imaging, medical imaging etc. According to the data we have, several methods are there to analyze the Image via multiple sensors to acquire the requires information from them. But when coming to the phase of multi-level image fusions the present transforms are not so efficient in depicting both the spatial and multispectral data, we here in our project are paving a method using Fast Discrete Curvelet Transforms (FDCT) where we fuse a Low Resolution (LR) Multispectral Image and High Resolution (HR) Panchromatic Image when we will map the spatial coordinates with multispectral details accordingly.

Pre-Requisites

Image

Image is a two-dimensional function of intensity and time where the real-world things, objects are captured of a particular instant. The Images are the easiest form of representing any form of things or objects or cast any data that is to be easily understandable. There are many types of images namely:

1. Binary Image
2. Gray-Scale Images/Panchromatic Images
3. Color Images
4. Multispectral Images

We in our project are using the Panchromatic image and as well as Multi-Spectral Images that were most found when coming to the point of Satellites. We here used a 5.8m LR Multispectral Image whose spectral resolutions can be varied as 56m, 23.3m, 5.8m with simultaneous acquisitions and we also use a 2.5m resolution base Panchromatic sensitive image with a wide range of wavelengths that are taking place into which typically spans into the larger part of visible spectrum.

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Satellites

A satellite is an object that moves around a larger object. Earth is a satellite because it moves around the sun. The moon is a satellite because it moves around Earth. Earth and the moon are called "natural" satellites. But usually when someone says "satellite," they are talking about a "man-made" satellite. Man-made satellites are machines made by people. These machines are launched into space and orbit Earth or another body in space. There are thousands of man-made satellites. Some take pictures of our planet. Some take pictures of other planets, the sun and other objects. These pictures help scientists learn about Earth, the solar system and the universe. Other satellites send TV signals and phone calls around the world.

We have various applications by satellites like:

1. Television Broadcasting Services
2. Tele-Communication & Broadband Services
3. Navigational Services
4. Business & Financial Services
5. Weather Services – Climate & Environmental Monitoring
6. Emergency & Safety Services
7. Space Science & Research based Applications

There are various types of satellites but when coming to this project we limit with two major types of Indian Remote Sensing Satellites by NRSA i.e. LISS-IV (Linear Imaging Self Scanning Sensor) and CARTOSAT – I (Cartography Satellite) which are Remotely Image Sensing Satellites that can capture multiple data from multiple set of sensors.

Transforms

When coming to process these images we earlier said about Digital Image Processing (DIP), here in the DIP we use various transforms like Fourier, PCA, Grams-Schmidt…etc. Transform is processing of images using mathematical operations by using any form of signal processing for which the input is an image, a cascaded set of images or a video, such as a photography orvideography frames, the output of image processing may be either a photo or a set of characteristic parameters of an image. Most image-processing techniques involve isolating the unique spectral planes of an image and treating them as two-dimensional signal and processing the using signal processing techniques. Images are also processed as three-dimensional signals with the thirddimension being time or the z-axis.

Transforms are most important when comes to process a Digital Image. All the computer graphics and computer vision which posteriorly are related to the Image processing are done by the various math principles that are constructed inside the transforms. We also often use them in the advanced scientific research visualizations often for large complex large-scale experimental data.

In our pre-requisites we shall discuss about the Transforms like Fourier, Wavelet, Curvelet and Fast Discrete Curvelet Transforms.

A. Fourier Transforms

The Fourier Transform is an important image processing tool which is used to decompose an image into its sine and cosine components. The output of the transformation represents the image in the *Fourier* or frequency domain, while the input image is the special domain equivalent. In the Fourier domain image, each point represents a particular frequency contained in the spatial domain image. The Fourier Transform is used in a wide range of applications, such as image analysis, image filtering, image reconstruction and image compression.

As we are only concerned with digital images, we will restrict this discussion to the Discrete Fourier Transform (DFT). The DFT is the sampled Fourier Transform and therefore does not contain all frequencies forming an image, but only a set of samples which is large enough to fully describe the spatial domain image. The number of frequencies corresponds to the number of pixels in the spatial domain image, *i.e.* the image in the spatial and Fourier domain are of the same size.

For a square image of size N×N, the two-dimensional DFT is given by:

$$F(k,l) = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} f(i,j)\ e^{-\iota 2\pi\left(\frac{ki}{N}+\frac{lj}{N}\right)}$$

where *f(a,b)* is the image in the spatial domain and the exponential term is the basis function corresponding to each point *F(k,l)* in the Fourier space. The equation can be interpreted as: the value of each point *F (k, l)* is obtained by multiplying the spatial image with the corresponding base function and summing the result.

Wavelet Transforms

A wavelet is a mathematical function used to divide a given function or continuous-time signal into different scale components. It is defined as, “A function is called an orthonormal wavelet if it can be used to define a Hilbert basis, that is a complete orthonormal system, for the Hilbert space of square integrable functions”. The fundamental idea of wavelet transforms is that the transformation should allow only changes in time extension, but not shape. This is affected by choosing suitable basis functions that allow for these changes in the time extension are expected to conform to the corresponding analysis frequency of the basis function. Based on the uncertainty principle of signal processing, where t represents time and ω angular frequency ω = 2πf, where f is temporal frequency. The higher the required resolution in time, the lower the resolution in frequency has to be. The larger the extension of the analysis windows is chosen, the larger is the value of,

When Δt is large,

1. Bad time resolution
2. Good frequency resolution
3. Low frequency, large scaling factor

When Δt is small

1. Good time resolution
2. Bad frequency resolution
3. High frequency, small scaling factor

Wavelet transforms are classified into *discrete wavelet transforms (DWTs)* and *continuous wavelet transforms (CWTs)*. Note that both DWT and CWT are continuous-time (analog) transforms. They can be used to represent continuous-time (analog) signals. CWTs operate over every possible scale and translation whereas DWTs use a specific subset of scale and translation values or representation grid.

C. Curvelet Transforms

Curvelets are based on multi scale ridge let's combined with a spatial band pass filtering operation to isolate different scales. This spatial band pass filter nearly kills all multiscale ridge lets which are not in the frequency range of the filter. In other words, a curvelet is a multiscale ridge let which lives in a prescribed frequency band. The band pass is set so that the curvelet length and width at fine scales are related by a scaling law 2 width ≈ length and so the anisotropy increases with decreasing scale like a power law. There is very special relationship between the depth of the multiscale pyramid and the index of the dyadic sub bands; the side length of the localizing windows is doubled at every other dyadic sub band, hence maintaining the fundamental property of the curvelet transform which says that elements of length about - / 2 2 j serve for the analysis and synthesis of the j- the sub band 1 [2, 2] j j+. While multiscale ridge lets have arbitrary dyadic length and arbitrary dyadic widths, curvelets have a scaling obeying 2 width ≈ length. Loosely speaking, the curvelet dictionary is a subset of the multiscale ridge let dictionary, but which allows reconstruction.

To construct a basic curvelet ϕ and provide a tiling of the 2-D frequency space, two main ideas should be followed:

Consider polar coordinates in frequency domain

To construct a basic curvelet with compact support near a ″basic wedge″, the two windows W and $\tilde{V}_{N_j}$ need to have compact support. Here, we can simply take to cover with dilated curvelets and $\tilde{V}_{N_j}$ such that each circular ring is covered by the translations of .

Then the admissibility yields

$$\sum_{j=-\infty}^{\infty} \left|W(2^{-j}r)\right|^2 = 1, r \in (0,\infty).$$

for tiling a circular ring into N wedges, where N is an arbitrary positive integer, we needa

2π -periodic nonnegative window $\tilde{V}_{N_j}$ with support inside such that $\left[\frac{-2\pi}{N}, \frac{2\pi}{N}\right]$

$$\sum_{l=0}^{N-1} \tilde{V}_N^2(\omega - \frac{2\pi l}{N}) = 1$$, for all $\omega \in [0, 2\pi)$

$\tilde{V}_N$ can be simply constructed as 2π-periodization's of a scaled window $V(\frac{N\omega}{2\pi})$.

Then, it follows that

$$\sum_{l=0}^{N_j-1} \left|2^{\frac{3j}{4}} \hat{\phi}_{j,0,0}(r, \omega - \frac{2\pi l}{N_j})\right|^2 = \left|W(2^{-j}r)\right|^2 \sum_{l=0}^{N_j-1} \tilde{V}_{N_j}^2(\omega - \frac{2\pi l}{N}) = \left|W(2^{-j}r)\right|^2$$

For a complete covering of the frequency plane including the region around zero, we need to define a low pass element

that is supported on the unit circle, and where we do not consider any rotation.

D.Fast Discrete Curvelet Transforms

Fast digital implementations of the second generation curvelet transform for use in data processing are disclosed. One such digital transformation is based on unequally-spaced fast Fourier transforms (USFFT) while another is based on the wrapping of specially selected Fourier samples. Both digital transformations return a table of digital curvelet coefficients indexed by a scale parameter, an orientation parameter, and a spatial location parameter. So, the complexity of the calculation as mentioned above will be reduced.

We shall see the necessary steps of creating the algorithm in the proposed work in the upcoming sections.

Image Fusion

The image fusion is one of the important branches of data fusion. Data fusion techniques have been designed not only to allow integration of different information sources, but also to take advantage of complementary. There is no unique definition for image fusion. Few image fusion definitions are given below:

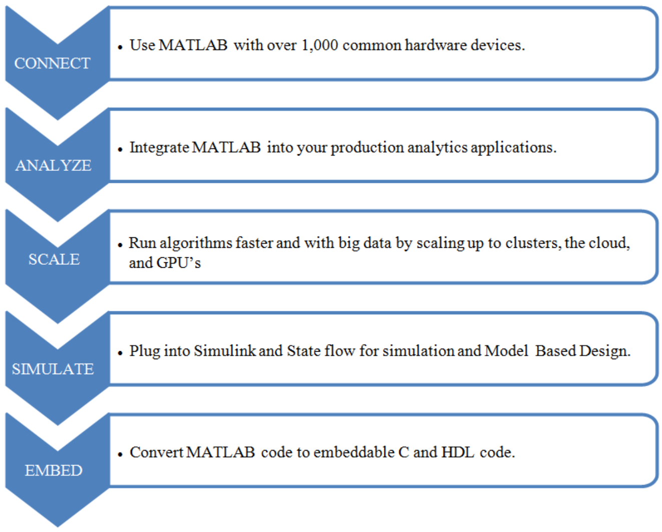
- "Image fusion is the combination of two or more different images to form a new image by using a certain algorithm!' (Genderen and Pohl 1994).
- "Image fusion is the process of combining information from two or more images of a scene into a single composite image that is more informative and is more suitable for visual perception or computer processing". (Guest editorial of Information Fusion, 2007).
- "Image fusion is a process of combining images, obtained by sensors of different wavelengths simultaneously viewing of the same scene, to form a composite image. The composite image is formed to improve image content and to make it easier for the user to detect, recognize, and identify targets and increase this situational awareness" 2010.Though there are various definitions of image fusion, more or less all definitions agree that image fusion is a process to obtain better content image from multiple images.
- The present thesis believes that the purpose of image fusion is to create a perceptually enhanced image from a set of multi-sensor images. Multi sensor images often have different geometric representations, which have to be transformed to a common representation for fusion.
- This representation should retain the best resolution of either sensor. The present thesis views image fusion as a process to Incorporate essential information from different modality sensors into a composite image.
- Provide an effective way of reducing the increasing volume of information while at the same time extracting all the useful information from the source images.
- Create new images that are more suitable for the purpose of human/machine perception, and for further image-processing tasks such as segmentation, object detection or target recognition.
- Enhance spectral resolution of PAN image and spatial resolution of MS image. Generally, benefits of sensor fusion are task dependent. Some potential benefits of image fusion are wider spatial and temporal coverage, decreased uncertainty, improved reliability, and increased robustness of the system.

Generic Requirements of Image Fusion are as follows,

1. The fused image should preserve as closely as possible all relevant information contained in the input images.
2. The fusion process should not introduce any artefacts or inconsistencies which can distract or mislead the human observer or any subsequent image processing steps.
3. The fused image should suppress to a maximum extent the irrelevant features and noise.
4. The fusion process should maximize the amount of relevant information in the fused image, while minimizing the amount of irrelevant details, uncertainty and redundancy in the fused image.

Software Used For This Project

We used the Matlab (Matrix Laboratory) as a software tool for this project where we have the provision of Image Processing toolbox sewed internally in it. The advantages of using the MATLAB is that,



Smart Art Graphic 1 Features of MATLAB

A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python.

Advantages

- MATLAB is an interpreted language for numerical computation
- It allows one to perform numerical calculations and visualize the results without the need for complicated and time-consuming programming.
- MATLAB allows its users to accurately solve problems, produce graphics easily and produce code efficiently.

Disadvantages

MATLAB is an interpreted language, it can be slow, and poor programming practices can make it unacceptably slow.

Existing Methods

In the existing methods over a decade we've been using Discrete Wavelet Transforms (DWT) to process the digital images from the satellites. This method offers a very good spectral quality of images but lacks in the Spatial complexity.

Image fusion methods are broadly classified into two domains namely spatial domain and Transform domain methods. The spatial domain has methods such as averaging, Brovey method, principal component analysis (PCA) and IHS. The disadvantage of these methods is that they produce spatial distortion in the fused image. Spatial distortion can be handled precisely by frequency domain approaches on image fusion. Transform domain methods include Multi resolution Analysis (MRA, such as Pyramid transforms (Laplacianpyramid, gradient pyramid, etc.), Wavelet transforms (Discrete wavelet transform, Multi wavelet transform, Complex wavelet transform, etc.) and Multi scale transforms such as Ridge let, Curvelet and Contourlet. These methods show an optimized performance when coming to the spatial and spectral quality of the fused image when compared to other spatial methods in terms of fusion.

Proposed Work

In our Proposed Method we are using the Images from the two satellites namely LISS-IV and CARTOSAT-I where the LISS-IV is a satellite that is very near to the earth and gives the Multi spectral Image of Low Resolution. On the other hand, we are having the CARTOSAT – I, which is placed in the mid-orbits and is capable of giving High Resolution Panchromatic (Black & White) Images. Moreover, these two satellites will be moving in a synchronous with very less time period difference so we can analyse them with no despair.

Working Model

In the present working model of the project we take the both images as the input to the system that is the LR multi spectral image and the HR Panchromatic image. Then they are undergone through the system that analyses that. To do that the image should be modulated in such a way that the noise elements are removed by the filters. Then the coarser-scale (low frequency) coefficients a_0, a_1…, $a_F$are used to represent the low frequency elements in the image.

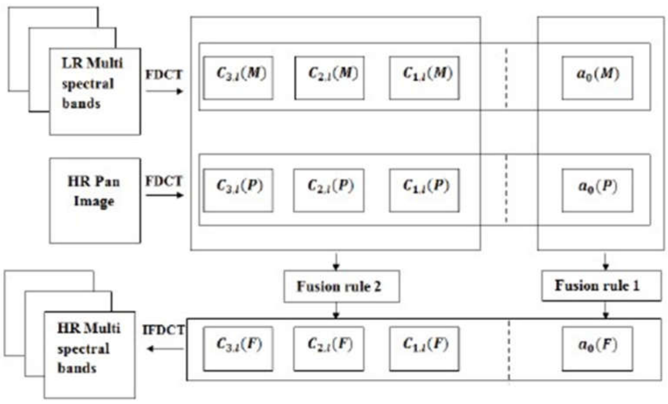


Fig 1 Block Diagram Explaining the Working of the FDCT Based Image Fusion of LR Multispectral & HR Panchromatic Images

In a provisional band of frequencies, bigger curvelet coefficients of HR Pan image and LR Multispectral image represent sharp local feature. In this project, we define a Local Magnitude Ratio (LMR) to inject high frequency details of the local image feature into the fused image. LMR is defined as follows.

Let us suppose that $c_{j,l}(M)$, $c_{j,l}(P)$ are the sub-band curvelet coefficients at scale j in a direction l of the multispectral band M and panchromatic image P at higher frequencies respectively.

$$LMR_{j,l}(x,y) = \frac{|c_{j,l}(M(x,y))|}{|c_{j,l}(P(x,y))|}$$

Where $LMR_{j,l}(x, y)$ is the sub-band curvelet coefficients at scale j in direction l at location (x,y). If $LMR_{j,l}(x, y) \leq 1$ then $c_{j,l}(P(x, y))$ represents good local feature. If $LMR_{j,l}(x, y) > 1$ then $c_{j,l}(M(x, y))$ represents good local feature. Fusion rule to inject high spatial details from HR panchromatic image into LR multispectral image bands is defined using LMR of curvelet coefficients in the directional high frequency sub-bands.

Image Fusion Algorithm using FDCT

Spatial resolution coefficient ratio between high resolution panchromatic image and low resolution multispectral image is 2, input images size must be powers of 2 for coherent and multi-resolution decomposition in FDCT domain. To obtain high resolution multispectral image, high frequency details are inserted into each low resolution multispectral band in FDCT domain. The fusion rule based on the L_{MR} in FDCT domain is defined as follows.

Algorithm

1. LR multispectral image is resampled to the scale of high resolution pan image in image co-registration. i.e., both the pictures must be at ideal and same geometry and of same size.
2. The multispectral data in Green colour, Red colour and near infrared bands are extracted band wise.
3. Apply fast discrete curvelet transform (FDCT) to multispectral band M and Panchromatic Image P.
4. The input images are decomposed into four levels in multiple directions.

   L_{MS} = {c3, l(M), c2, l(M), c1, l(M), a0(M)}
   H_{Pan} = {c3, l(P), c2, l(P), c1, l(P), a0(P)}

Number of directions depends on the image size and decomposition levels. where L_{MS} is the set of curvelet coefficients for low resolution multispectral band, where H_{Pan} is the set of curvelet coefficients for high resolution panchromatic image and $a_0(M)$ is the coarser scale co-efficient of the multispectral band M, similarly $a_0(P)$ for the panchromatic image P.

5. Fusion rule 1 is defined for the curvelet coefficients at lower frequencies (coarser scale coefficients). Construct coarser scale coefficients for fused image F from LR multispectral band M such that,

   $$a_0(F) = a_0(M)$$

6. Fusion rule 2 is elaborated for the curvelet coefficients at higher-end frequencies based on high pass modulation. Construct the multidirectional multiresolution curvelet coefficients $c_{j,\,l}(F)$ by using the below equation as follows for fused image.

$$c_{j,l}(F(x,y)) = \begin{cases} c_{j,l}(P(x,y)).*LMR_{j,l}(x,y) & \text{if } LMR_{j,l}(x,y) > 1; \\ c_{j,l}(P(x,y)) & \text{if } LMR_{j,l}(x,y) \leq 1; \end{cases}$$

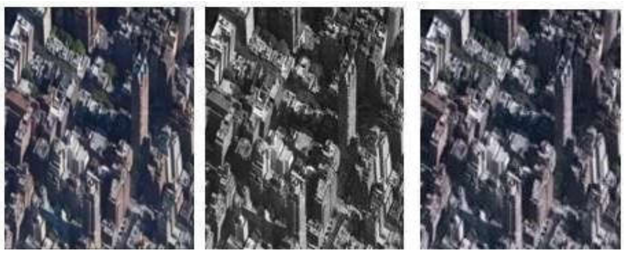
7. Construct the set of curvelet planes for fused image as, $\mathbf{H_{Fus} = \{c_{3,l}(F), c_{2,l}(F), c_{1,l}(F), a_0(F)\}}$ and apply the Inverse Fast Discrete Curvelet Transforms (IFDCT).
8. Apply steps (3) to (6) for each multispectral band.
9. Combination of three responsive and resultant fusion of bands provide the HR multispectral fused image as an output.

By Implementing the above steps, we will obtain the FDCT image fusion-based Satellite image as output where it is capable of various multispectral details with rich spatial details as well as it is also capable of a very high resolution with linear and curved details asserted accurately.

For the FDCT-based fusion method, Resource Sat -1 LISS IV image is taken as LR multispectral image which is Orth rectified and resampled to 5m spatial resolution and Cartosat1 data is taken as an HR Pan image of resolution 2.5m. Both of these images are in 1:2 scale ratio. HR Pan Image size is 2048×2048 and LR multispectral image size is 1024 × 1024. For clear visualization, subset images of the fused image of FDCT technique.

RESULTS

It is the original HR Pan Cartosat-1 image and is the resampled LR multispectral image. The 3rd is the HR multispectral image obtained by new fusion rule based on FDCT. The values obtained by the wavelet transform, PCA, HPF, Modified IHS and Grams-Schmidt fusion techniques respectively implemented in Earth Resources Data Analysis System (ERDAS 2013) satellite image processing software is taken for comparison.



a) LISS IV **b) Cartosat-I** **c) FDCT**

Fig 2 Colour compositions of full-scale fusion results for the reported detail (NIR, Red, and Green bands as R, G, and B channels Quality of the fused images is evaluated with both spatial and spectral quality measures.

Project Results

The FDCT Based Image Fusion has been applied to an Image that is consisting of LR bands of Multiple Spectra and HR Panchromatic Spatial Image. This will be discussed as follows.

Fig 3 Input Low Resolution Image with Multiple Spectra

This is the Low Resolution (LR) image which is consisting of Multiple Spectrum that is captured from the LISS – IV based Satellite (Resourcesat – I).

Fig 4 Input High Resolution Panchromatic Image

This is the High Resolution (HR) Panchromatic image which has rich spatial details of the place captured from the CARTOSAT – I Satellite. When these both are given as the inputs to the system i.e. FDCT based image fusion system (or algorithm) then the co – registration of the image is formed as follows.

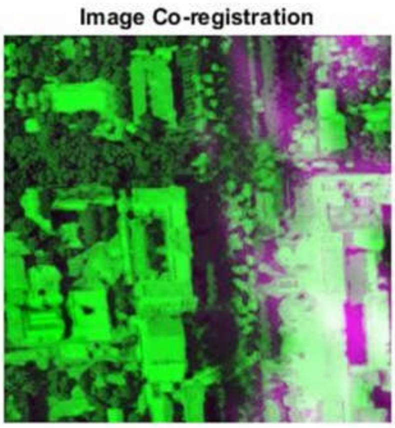


Fig 5 Image Co - Registration of the inputs applied

Then the FDCT algorithm is applied up on the images subsequently so that we can get the Horizontal, Vertical and Diagonal coefficients with respect to the approximations of the coarser-scale coefficients.

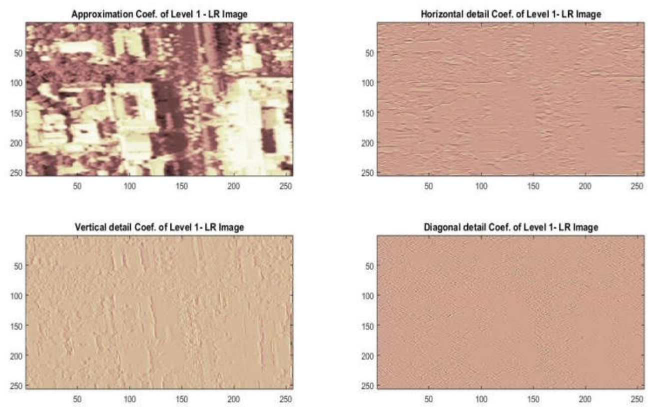


Fig 6 Coefficients of LR Multispectral Image including approximation coefficient values

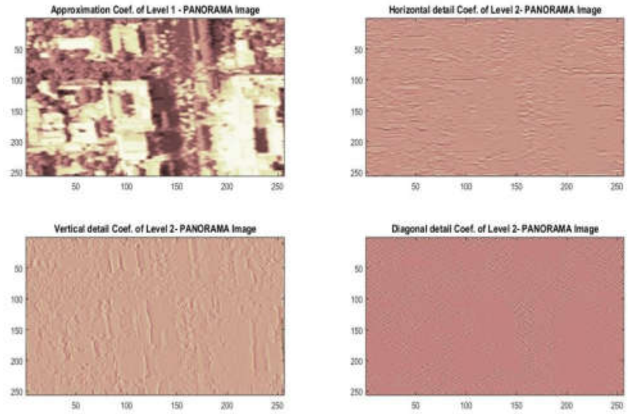


Fig 7 Coefficients of HR Panchromatic Image including approximation coefficient values

Based upon these coefficients the fusion will be occurred and inverse transform will be applied on it to resolve it and the fused image is given as the output.

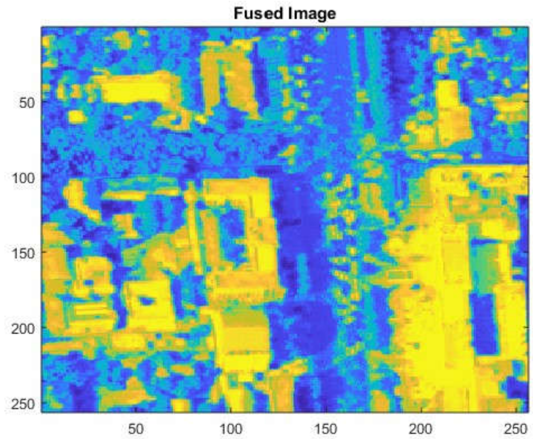


Fig 8 Fused image after the processing of the image using FDCT

Standards Comparison

We generally evaluate the standards based on two modes

1. Spatial quality Evaluation
2. Spectral Quality Evaluation

Spatial Quality Evaluation

Each MS band in a fused image is compared to the HR Pan image for spatial quality evaluation.

Entropy

Entropy is a measure to directly conclude the performance of image fusion. The Entropy can show the average information included in the image and reflect the detail information of the fused image. Generally, the more the entropy of the fused image is, the more abundant information included in that, the higher the quality of the fusion. According to the information theory of Shannon, the entropy of image is defined as,

$$E = -\sum_{i=0}^{n} p_i \log_2 p_i$$

Where E is the entropy of image and pi is the probability of i in the image, here pi is the frequency of pixel values from 0 to n in the image. We normalized the HR Pan data and LR MS data radiometric resolutions. Entropy values band wise are shown in Table 1.

Table 1 Entropy

Band	FDCT	Wavelet	PCA	HPF	MIHS	GS
1	6.22	5.91	5.66	5.89	6.09	5.85
2	6.78	6.55	6.81	6.68	6.70	6.79
3	6.29	6.15	6.20	6.12	6.12	6.11
Average	6.43	6.21	6.23	6.23	6.30	6.25

Correlation coefficient of high pass filtered images

High frequency details from the Pan image are compared to the high frequency details from each band of the fused images using a method proposed by Zhou et al. To extract the high frequency data, apply the following convolution kernel to the images

$$mask = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

The coarser correlation coefficients between the HPF based fused bands and the HPF Pan image is used as an index of the spatial quality. The principle is that the spatial information unique in Pan image is mostly concentrated in the high frequency component of Pan image has been inserted into the fusion. Coarser correlation coefficients of HPF images based upon band-wise together are shown in Table 2.

Table 2 Correlation coefficient of high pass filtered images

Band	FDCT	Wavelet	PCA	HPF	MIHS	GS
1	0.97	0.17	0.99	0.82	0.90	0.01
2	0.98	0.18	0.93	0.92	0.92	0.96
3	0.97	0.19	0.39	0.83	0.87	0.94
Average	0.97	0.18	0.77	0.86	0.90	0.64

Average Gradient

Spatial quality of fused image f by average gradient can be calculated by using the equation,

$$ag = \frac{1}{(M-1)(N-1)} \sum_{x=1}^{M-1} \sum_{y=1}^{N-1} \sqrt{\frac{|\frac{\partial f(x,y)}{\partial x}|^2 + |\frac{\partial f(x,y)}{\partial y}|^2}{2}}$$

Where f (x, y) is the pixel value of the fused image at position (x, y). The average gradient reflects the clarity of the fused image. It can be used to measure the spatial resolution of the fused image, i.e., a larger average gradient indicates higher the spatial resolution. The results of the Average gradient values band-wise are shown in Table 3.

Table 3 Average Gradient

Band	FDCT	Wavelet	PCA	HPF	MIHS	GS
1	4.41	3.96	3.25	3.21	4.10	2.90
2	4.63	4.05	5.44	4.28	4.38	5.21
3	4.43	3.93	4.52	3.65	3.54	4.28
Average	4.49	3.98	4.40	3.71	4.01	4.13

Spectral Quality Evaluation

Resampled multispectral bands of LISS-IV sensor image and corresponding bands in the fused image are compared for spectral quality evaluation.

Spectral Angle Mapper (SAM)

Let v and ˆv be two vectors having l components of resampled multispectral LISS-IV sensor band and the corresponding band in the fused image respectively. Spectral angle mapper (SAM) is the absolute value of the angle between the two vectors.

$$SAM(v, \hat{v}) = cos^{-1}\left(\frac{\langle v, \hat{v}\rangle}{\|v\|_2 . \|\hat{v}\|_2}\right)$$

It is calculated in degrees or radians and is usually averaged over the total image to yield an all over measurement of spectral distortion. All these values equals to zero denotes the absence of spectral distortion. Table 4 shows the values for each fused band.

Table 4 Spectral Angle Mapper (SAM)

Band	FDCT	Wavelet	PCA	HPF	MIHS	GS
1	0.04	0.07	0.06	0.03	0.08	0.02
2	0.05	0.07	0.21	0.05	0.11	0.17
3	0.03	0.06	0.11	0.04	0.06	0.09
Average	0.04	0.07	0.13	0.04	0.08	0.10

Universal Image Quality Index (UIQI)

Let A and B be the resampled satellite low resolution sensor band and the corresponding band in the fused image respectively. The Universal Image Quality Index is defined by Wang and Bovik (2002) as,

$$Q = \frac{\sigma_{AB}}{\sigma_A \sigma_B} . \frac{2 m_A m_B}{(m_A)^2 + (m_B)^2} . \frac{2 \sigma_A \sigma_B}{(\sigma_A)^2 + (\sigma_B)^2} .$$

Where σ^2_A, σ^2_B are the variances of images A and B respectively, $\sigma_{AB}$is the covariance of the given input images A and B , m_A, $m_B$are mean of the images A and B respectively. The more the value of UIQI indicates the better fusion quality given by the method. UIQI values for each band are shown in Table 5. When coming to our proposed method, has scored better than other methods.

Table 5 Universal Image Quality Index (UIQI)

Band	FDCT	Wavelet	PCA	HPF	MIHS	GS
1	0.18	0.10	0.07	0.12	0.08	0.12
2	0.13	0.05	0.06	0.07	0.05	0.06
3	0.14	0.11	0.10	0.10	0.18	0.09
Average	0.15	0.08	0.08	0.10	0.11	0.09

Comparisons, Merits & Demerits

When we have processed through the image via FDCT Algorithm the differences that we have found in this are as follows,

Existing Methods	Proposed Method
Takes More Iterations(Time Complexity is more).	Takes Less Iterations(Time Complexity is Less).
Less Optimization when compared to FDCT.	Decent Optimization of Image with HR.
Resolution Increasing factor is not appropriate.	Resolution Increasing factor is good.
Fails to represent Curve - Linear structures effectively.	Curve – Linear structures are represented effectively.
Poor Signal to Noise Ratio (SNR).	Gives good SNR Value.
It Cannot Illustrate Multi-Level Fusion.	It Supports Multi-Level Fusion.

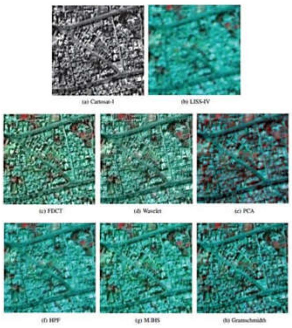


Fig 9 Fig Representing Various Transforms in comparison with FDCT

Advantages of FDCT

- Gives eminent Entropy Values for the Images
- Accurate Correlation of High Pass Filtered Images.
- Spatial Quality Average Gradient of the Image is more than the previous methods.
- The Spectral Angle Mapping is higher for individual bands.
- FDCT has better score Universal Image Quality Index(UIQI) when compared to all the other methods.
- It can act upon lower resolution Images as well as Higher Resolution Images as well.
- Time consumption is less when compared to the previous Transforms.
- *Disadvantages of FDCT*
- System Becomes More Complex when going on for Multiple Multispectral Image Processing.
- Requires Two different forms images at least to process.

CONCLUSION

The proposed multilevel image fusion algorithm based on FDCT works efficiently for fusion of Satellite Images as well also for multi-sensory applications. In this paper, the comparison of DWT and FDCT as well as some other techniques is done by tabular and graphical representation which shows improved fusion quality by statistical analysis of quality metrics parameters.

The FDCT based multilevel Satellite image fusion works better than DWT based multilevel mage fusion. The terms of enhanced visual quality, richness of information content in fused image, is better than that of previous based transform techniques. The future work includes, implementing other fusion methods based on latest multi scale geometric analysis transform and some improvements in pre-as well as post processing of image fusion and as well as incorporating multiple transforms into this like combinations to produce genetic level architecture that simplifies the work more affluently.

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