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SATTELITE IMAGE FUSION IN FAST DISCRETE CURVELET TRANSFORM DOMAIN

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Abstract

Image fusion based on the Fourier and wavelet transform methods retain rich multispectral details but less spatial details from source images. Wavelets perform well only at linear features but not at non linear discontinuities because they do not use the geometric properties of structures. Curvelet transforms overcome such difficulties in feature representation. In this paper, we define a novel fusion rule via high pass modulation using Local Magnitude Ratio (LMR) in Fast Discrete Curvelet Transforms (FDCT) domain. For experimental study of this method Indian Remote Sensing (IRS) Resourcesat-1 LISS IV satellite sensor image of spatial resolution of 5.8m is used as low resolution (LR) multispectral image and Cartosat-1 Panchromatic (Pan) of spatial resolution 2.5m is used as high resolution (HR) Pan Image. This fusion rule generates HR multispectral image at 2.5m spatial resolution.

Keywords—*Image Fusion, Fast Discrete Curvelet Transforms, Local Magnitude Ratio (LMR)*

I. INTRODUCTION

Image fusion integrates the multisensor data to create a fused image containing high spatial, spectral and radiometric resolutions. In remote sensing, image fusion is most valuable technique for utilization of multisensor, multispectral at various resolutions of earth observation satellites [10]. Spatial resolution plays a vital role to delineate the objects in the remote sensing image. It is easy to interpret the features with high spatial resolution [20] image with multispectral information than the single high resolution Pan image. Image fusion enhance the spatial, spectral and radiometric [11] resolutions of images.

There are several satellite image fusion Techniques but spatial and spectral details retention simultaneously is a trade off. F.Nencini et al. [5] proposed a fusion method based on interband structure model (IBSM) in first generation curvelet transform domain. The method uses Quick-bird and Ikonos multispectral and Pan Images. The experimental results shown that, the method slightly better than the Atrous Wavelet Transform (ATWT) and outperform Grams-Schmidt spec-tral sharpening method. Ying Li et al. [6] proposed a Fast Discrete Curvelet Transform (FDCT) based remote sensing image fusion. The method uses Synthetic Aperture Radar (SAR) and Thematic Mapper(TM) images for fusion. This work concluded that FDCT based fusion method retain good spatial details and simultaneously preserve the rich spectral content compared with Discrete Wavelet Transform (DWT) and Intensity-Hue-saturation (IHS). Arash Golibag et al. [7] focuses on region based image fusion using linear dependency decision rule based on Wronskian determinant. The method uses multispectral Landsat and IRS Pan Images for fusion. Shutao Li et al. [8] have done multifocus image fusion by combining curvelet and wavelet transform. Cai Xi [9] proposed FDCT based image fusion by using Support Vector Machines (SVM) and Pulse Coupled Neural Network (PCNN) to narrate the good sensitivity to boundaries of objects, concluded that the method has better performance than FDCT.

Fast Fourier and wavelet transform based image fusion methods retain better spectral characteristics but represent poor spatial details in fused images. Objective of this paper is to develop a method, which retains better characteristics of both spatial and spectral qualities of source images. Wavelet transforms do not represent the curved objects as in HR Pan Image. Curvelet transforms overcome such difficulties of wavelet. Over a period, curvelet transforms are evolved in two generations, such as first generation curvelet transforms and second generation curvelet transforms named as Fast Discrete Curvelet Transforms (FDCT).First generation curvelet transforms computational complexity is more to compute the curvelet coefficients [5]. To overcome these difficulties Emmanuel J.Candes [1] developed FDCT. FDCT represents linear-edges and curves accurately than any other mathematical transforms.

II.PROPOSED APPROACH

In a directional sub-band, bigger curvelet coefficients of HR Pan image and LR multispectral image represent sharp local feature [19]. In this paper, 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 $cj,l(M)$, $cj,l(P)$ 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.

$$LMRj,l(x, y) =|cj,l(M(x, y))||cj,l(P(x, y))|$$

Where $LMRj,l(x, y)$ is the sub-band curvelet coefficients at scale j in direction l at location (x,y).
If $LMRj,l(x, y) \leq 1$ then $cj,l(P(x, y))$ represents good local feature. If $LMRj,l(x, y) > 1$ then $cj,l(M(x, y))$ 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 inthe directional high frequency sub-bands.

III.IMAGE FUSION ALGORITHM USING FDCT

Spatial resolution ratio between HR Pan image and LR multispectral image is 2. Input images size must be power of 2 for coherent multi resolution decomposition in FDCT domain. To obtain HR multispectral image, high frequency details are injected into each LR multispectral band in FDCT domain. The fusion rule based on the LMR in FDCT domain is defined as follows.

- LR multispectral image is resampled to the scale of HR Pan Image in image co registration. i.e., both the images must be at identical geometry and of same size.
- The multispectral data in Green, Red and near-infrared bands are extracted band wise.
- Apply fast discrete curvelet transform (FDCT) to multispectral band M and Panchromatic image P. The input images are decomposed into four levels in multiple directions. Number of directions depends on the image size and decomposition levels.

  $L_{MS} = \{c_{3,l}(M), c_{2,l}(M), c_{1,l}(M), a_0(M)\}$

  $H_{Pan} = \{c_{3,l}(P), c_{2,l}(P), c_{1,l}(P), a_0(P)\}$

  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 coefficients of the multispectral band M, similarly $a_0(P)$ for the panchromatic image P .

- 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 $a_0(F) = a_0(M)$
- Fusion rule 2 is defined for the curvelet coefficients at higher frequencies based on high pass modulation. Construct the multidirectional multiresolution curvelet coefficients $c_{j,l}(F)$ by using Equation (7) for fused image.
- Construct the set of curvelet planes for fused image as

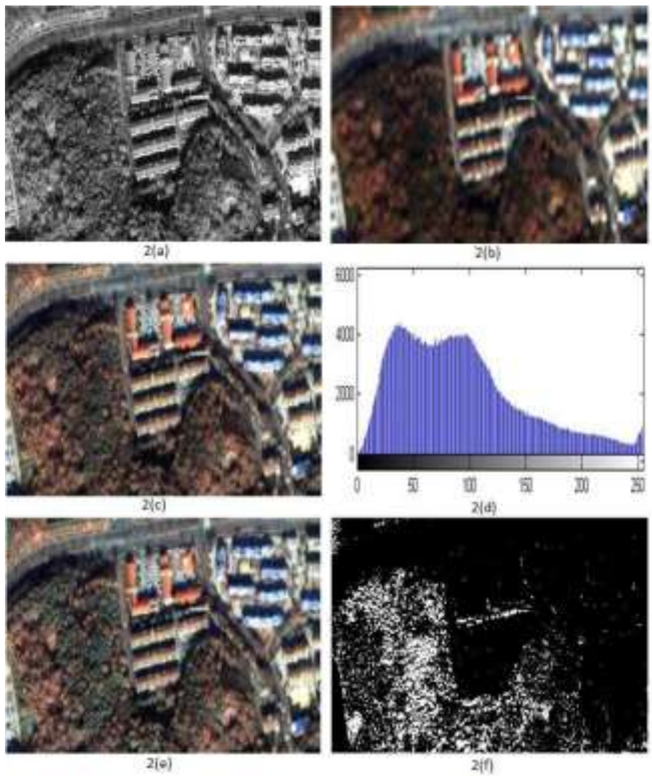
  $H_{Fus} = \{c_{3,l}(F), c_{2,l}(F), c_{1,l}(F), a_0(F)\}$

  And apply the Inverse Fast Discrete Curvelet Transforms (IFDCT).
- Apply steps (3) to (6) for each multispectral band.
- Combination of three resultant fused bands provide the HR multispectral fused image .
- Apply steps (3) to (6) for each multispectral band.
- Combination of three resultant fused bands provides the HR multispectral fused image.

IV. EXPERIMENTAL RESULTS

a

b



FDCT Fusion images 2(a) Panchromatic image, 2(b) Multispectral image, 2(c) Fused image of existing method 2(d) Histogram of fused image, 2(e) Fused image of enhanced method 2(f) Vegetation area extracted from enhanced fused high resolution Multispectral image

A. Spatial Quality Evaluation

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

1) 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. Commonly, the greater the entropy of the fused image is, the more abundant information included in it, and the greater the quality of the fusion. According to the information theory of Shannon, the entropy of image is defined as

$$E = -\sum_{i=1}^{n} p_i \quad log_2 \quad p_i$$

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 LRMS data radiometric resolutions.

2) Average gradient: Spatial quality of fused image *f* by Average gradient can be calculated by using the equation

$$A_g = \frac{1}{(a-1)(b-1)} \sum_{x=0}^{a-1} \sum_{y=0}^{b-1} \sqrt{\frac{\left|\frac{\delta f(x,y)}{\delta x}\right|^2 + \left|\frac{\delta f(x,y)}{\delta n}\right|^2}{2}}$$

Where *f*(*a*,*b*) is the pixel value of the fused image at Position (*a*,*b*). 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.

B. Spectral Quality Evaluation

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

1) Spectral Angle Mapper(SAM): Let *P* and Q be two Vectors having *l* components of resample 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 [5]. SAM is measured in either degrees or radians and is usually averaged over the whole image to yield a global measurement of spectral distortion. SAM values equal to zero denotes the absence of spectral distortion.

$$SAM(P,Q) = \cos^{-1}\left(\frac{\langle P,Q \rangle}{\langle \|P\|2 . \|Q\|2 . | \rangle}\right) \text{ degree or radian}$$

V. CONCLUSION

We have described new fusion method based on fast discrete curvelet transforms (FDCT). Two fusion rules are defined, fusion rule 1 is for curvelet coefficients at lower frequencies and fusion rule 2 is for the curvelet coefficients at higher frequencies. Fusion rule 1 substitute the coarser scale coefficients of LR multispectral bands into the coarser scale coefficients of HR Pan Image. Fusion rule 2 is based on the high pass modulation using Local Magnitude Ratio (LMR) of the curvelet coefficients in each orientation and scale. Bigger curvelet coefficients of HR Pan Image and LR multispectral image represent sharp local feature. LMR directs the injection of high frequency details of the local image feature in HR Pan Image into fused image. For experimental study of this method Indian Remote Sensing (IRS) Resourcesat-1 LISS IV satellite sensor image of spatial resolution of 5.8m is used as low resolution (LR) multispectral image and Cartosat-1
Panchromatic (Pan) of spatial resolution 2.5m is used as high resolution (HR) Pan Image. This fusion rule generates HR multispectral image at 2.5m spatial resolution.

TABLE I: SPATIAL QUALITY EVALUATION

Performance Parameter	Existing method	Proposed method
Entropy	7.4774	7.7511
Average gradient	4.3516	4.3655

TABLE II: SPECTRAL QUALITY EVALUATION

Performance parameter	Existing method	Proposed method
Spectral Angle Mapper	0.90238	0.89541

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