Analysis of the Effect of Incidence Angle variation in Fusion of SAR images with Multispectral image using Empirical Mode Decomposition

A. DALRIN AMPRITTA, S. S. RAMAKRISHNAN
Institute of Remote Sensing, Department of Civil Engineering, College of Engineering, Anna University, Chennai, Tamil Nadu, India
Email: amprimritiam@gmail.com, ssramki@annauniv.edu

Abstract: In the field of Remote Sensing and GIS, colour images of high resolution in the form of aerial photos or satellite images are desired for visually interpreting various features in our environment, but are limited due to their expensiveness. On the other hand, SAR images of high resolution are available at a comparatively lower cost. With the increasing demand for better image quality, lot of image processing algorithms have been designed for analyzing optical and SAR images. In the image fusion process multi-sensor outputs can be combined to give a better quality image of the area. The purpose of fusion process is to synthesize a new multispectral image, whose bands coincide as much as possible with those of the original multispectral image, and with a spatial resolution comparable to the radar image. Currently, the most used image fusion techniques are IHS (Intensity Hue Saturation), Wavelet Transform, and PCA (Principal Component Analysis). It is evident that the employed methods seem to work well for single-sensor, single-date fusion. However with radar and multispectral data from different sensors or dates, these fusion methods create images of higher spatial resolution, but usually at the cost of the original colour or spectral characteristics of the input images. This is especially true if two completely different sensors are used. So new algorithms are required to overcome these problems and establish superiority over the standard fusion techniques. In this paper, the effect of variation in incidence angle of three SAR images which are fused separately with the multispectral image is studied. The analysis is done based on the capability of performing visual land use interpretation using each of the fused images. For the fusion process, a new algorithm based on 2D EMD (Two Dimensional Empirical Mode Decomposition) is coded using Matlab software. EMD is a non-parametric data-driven analysis tool that decomposes the single band radar image into high frequency IMFs (Intrinsic Mode Functions). This algorithm then combines the IMFs generated from the radar (SAR) image with the optical (multispectral) image, thus obtaining the fused image. The implementation of this algorithm is done by using ERS – 2 SAR and Landsat ETM+ images of Mansadevi region in Himachal Pradesh, India. Finally, Quality assessment of Empirical Mode Decomposition Algorithm with Conventional Fusion Techniques is done by using a statistical metric technique – Universal Image Quality Index.

Keywords: Image Fusion, Radar image, Optical image, Intrinsic Mode Function, Empirical Mode Decomposition, Incidence angle.

1.0 Introduction
A major application of remote sensing is the identification of land use/cover changes to see the impacts on environmental changes. However, depending on the image properties, there are some restrictions in the use of remotely sensed data. Due to the limitation of low resolution, it is difficult to produce land use/cover maps from optical images. Using merely optical image or SAR image is useful only in defining some of the objects. Although new generation satellite imagery has yet begun to progress with their good resolutions, remote sensing techniques are not as successful as expected in monitoring vast areas with varying slopes. Generally, obtaining better accuracy is the main target in mapping and in the classification of objects. Since optical and microwave sensors respond to very different characteristics, fusion of the two images could be used in classifying features with better accuracy. Image fusion is a technique used to integrate the geometric detail of a high-resolution SAR image and the colour information of a low-resolution optical image. The goal is to obtain a high-resolution optical image which combines the spectral characteristic of the low-resolution data with the spatial resolution of the SAR image. An effective image fusion technique can virtually extend the application potential of such remotely sensed images, as many remote sensing applications require both high-spatial and high-spectral resolutions, especially for environmental monitoring.

1.1 Objective and scope:
This study analyzed the impact of incidence angle variation in SAR images over the three image fusion techniques by Quality Assessment of the various fusion techniques using Universal Image Quality Index. The overall objective of the study was to fuse the three Synthetic Aperture Radar (SAR) images of different incidence angle with Landsat Multispectral image using Conventional Fusion Techniques namely
Intensity Hue Saturation Transform and Wavelet Transform to compare with the same images fused using Empirical Mode Decomposition Algorithm. The result of Empirical Mode Decomposition Algorithm was validated with convention fusion technique.

2.0 Study area and materials

2.1 Study area

The study area is Mansadevi region in Himachal Pradesh, India. The geographical location of the study area is at 78°10'25''E longitude and 29°56'33''N latitude.

![Study Area Image](image)

Figure 2.1 Study Area

2.2 Materials

The fusion of SAR and optical images requires Landsat TM and ERS-2 data as described in table 2.1.

Table 2.1 Characteristics of satellite data used

<table>
<thead>
<tr>
<th>Satellite ID</th>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
<th>Temporal Resolution</th>
<th>Polarization</th>
<th>Incidence Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat -5 TM</td>
<td>30m</td>
<td>7 bands</td>
<td>14/03/2000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ERS-2</td>
<td>25m</td>
<td>Gray Scale</td>
<td>28/07/2003</td>
<td>VV</td>
<td>35-42 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>29/03/2004</td>
<td>VV</td>
<td>25-42 deg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>03/05/2004</td>
<td>VV</td>
<td>33-50 deg</td>
</tr>
</tbody>
</table>

In this paper, in addition to image fusion for the purpose of environmental monitoring using improved image quality, the effect of incidence angle variation in three ERS-2 SAR images on fusion separately with optical image using Empirical Mode Decomposition Algorithm is studied. The analysis is based on the capability of performing visual interpretation of features using each of the fused images. Validation is done using conventional fusion techniques such as Intensity Hue Saturation (IHS) Transform and Wavelet Transform and quality assessment of all the techniques. It is of notable importance to remember the fact that the effect of incidence angle varies with the radar sensor used.

3.0 Image fusion by empirical mode decomposition algorithm

3.1 Methodology

The flowchart for the overall methodology of this study is given in figure 3.1.
4.0 Results and discussions

4.1 Image fusion by IHS Transform

![Image fusion by IHS Transform](image_url)

**Figure 4.1 Image fusion by Intensity Hue Saturation (IHS) Transform**

4.1.1 Incidence angle effect on agriculture and plantation

From the three fused images in figure 4.2, it can be seen that the radar shadow effect due to foreshortening and layover is most high for the image that has been fused using the radar image of highest incident angle.

The IHS Transform has improved in classifying the agricultural and plantation sites by incorporating new tones in locations that have different features associated with them. The effect of radar shadow decreases with decrease in incidence angle of the radar image which has a corresponding effect on the fused image.
4.1.2 Incidence angle effect on settlement and built up land
The IHS Transform has improved in classifying the fused image by a visible variation of tones in the area corresponding to settlement, buildings and roads as shown in figure 4.3. High incidence angle imagery was hence not conductive to settlement detection. The fused image with the intermediate incidence angle is considered to be the best fit for identifying settlements.

4.1.3 Incidence angle effect on Water body
At smaller incidence angles, the specular reflection from the standing water gives very high radar return in the image. This is because smooth water surfaces act as specular reflectors of radar wave. However for the given SAR image that has been fused with the optical image by IHS transform; there is no visible difference between the three fused images. This is attributed to the multi sensor effect on IHS Transform, which produces quality images only with single sensor fusion.
4.2 Image fusion by Wavelet Transform

4.2.1 Incidence angle effect on agriculture and plantation
It is noticeable that the radar shadow caused by foreshortening and layover effects has a severe effect on the fused image with higher incidence angle in the range 30 to 55 degree. On the other hand, when the incidence angle falls in the intermediate range, homogenous features like agricultural fields along with their borders are clearly visible with minimal effects of foreshortening, layover and shadow.

4.2.2 Incidence angle effect on settlement and built up land
Shadow effect caused by foreshortening and layover effects is seen to be much higher in the fused image corresponding to highest incidence angle, due to the presence of buildings and other built up land in the area. Thus it can be inferred that it is not advisable to fuse multi sensor images of high incidence angle using Wavelet and that the regions with shadow correspond to areas with taller settlements. Intermediate incidence angle is best suited for fusion using Wavelet Transform as it clearly distinguishes fallow land from settlements and has reduced shadow effect.

Figure 4.5 Image fusion by Wavelet Transform

Fused image 1 (33-52 deg)  Fused image 2 (30-50 deg)  Fused image 3 (25-42 deg)

Figure 4.6 Incidence angle effect on agriculture and plantations

Figure 4.7 Incidence angle effect on settlement and built up land

Fused image 1 (33-52 deg)  Fused image 2 (30-50 deg)  Fused image 3 (25-42 deg)
4.2.3 Incidence angle effect on Water body
The results obtained show that shadow effect is present for both fused images with high incidence angles. The fused image with intermediate incidence angle produces improved contrast that the optical image. Thus it is found that Wavelet Transform is used to visually enhance the contrast of the fused image from the two multi sensor source images.

4.3 Image fusion by EMD Algorithm

4.3.1 Incidence Angle effect on agriculture and plantation
The shadow present in the first two images is because of plantation sites present at the locations.

Thus it can be inferred that for multi sensor images, EMD Algorithm can be used to obtain better result with its variable parameters for Agriculture and plantation sites that with conventional techniques namely IHS and wavelet transforms.

4.3.2 Incidence Angle effect on settlement and built up land
Settlement is best enhanced using radar images of C band VV polarization. Hence in comparison with the original optical image, radar image as well as the fused images obtained using IHS Transform and Wavelet Transforms; better quality fused image for settlement area is obtained using EMD transform. This results in improved visual quality of the fused image with intermediate incidence angle as compared with the fused images of high incidence angle, whose quality has been compromised by the radar shadow effects of the settlements in the study area.
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4.3.3 Incidence Angle effect on Water body
Shadow effect at the canopy present nearby the water body produces dark tones in the images with high incidence angles. The shadow effect is compromised in the fused image with intermediate incidence angle.

Thus, for multi sensor images, EMD algorithm is seen to be best suitable for classifying agricultural and settlement area as compared with the water body. Fusion results vary with the specification of the radar sensor and the algorithm used.

The features that have been identified from the images fused as a result of IHS Transform, Wavelet Transform and EMD Algorithm have been validated from the corresponding Google earth image as shown in figure 4.13.

4.4 Result validation by quality assessment:

<table>
<thead>
<tr>
<th>Quality Index</th>
<th>IHS Transform</th>
<th>Wavelet Transform</th>
<th>EMD Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fused Image 1</strong>&lt;br&gt;(θ = 33 – 52 deg)</td>
<td>0.69</td>
<td>0.51</td>
<td>0.85</td>
</tr>
<tr>
<td><strong>Fused Image 2</strong>&lt;br&gt;(θ = 30 – 50 deg)</td>
<td>0.72</td>
<td>0.53</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>Fused Image 3</strong>&lt;br&gt;(θ = 25 – 45 deg)</td>
<td>0.79</td>
<td>0.57</td>
<td>0.91</td>
</tr>
</tbody>
</table>
**Conclusion:**
For the purpose of improved accuracy in detecting environmental changes and for environmental monitoring, high resolution optical images are desired. To improve the quality of optical images, image fusion has been carried out using the optical and SAR images of varying incidence angle for the Mansadevi region in Himachal Pradesh, India for the years 2003 and 2004. The conventional fusion techniques that have been used for better feature interpretability include Intensity-Hue-Saturation Transform and Wavelet Transform. This study uses Empirical Mode Decomposition Algorithm as an improved technique for fusing each of the three SAR images with the optical image. Validation of the impact of incidence angle over the fused image quality is done using Universal Image Quality Index as the Quality Assessment parameter. This study experimentally states that the quality index obtained using each of the fusion techniques decreases with increasing incidence angle of the sensor (negatively correlated). This study recommends the following point to improve the quality of the fused image: the ERS-2 SAR image used for fusion with the optical image should have an incidence angle in the intermediate range so as to reduce foreshortening, layover and shadow effects.

**Scope for future study:**
- The image fusion has been performed optical satellite data such as Landsat TM data of spatial resolution 30m and SAR data of 25m spatial resolution. But the environmental monitoring and feature interpretation can be further improved by using high resolution SAR data.
- The study area belongs to Himachal Pradesh where clouds are continuously presenting and optical satellites fail to penetrate them. This is resolved by using Synthetic Aperture Radar data of ERS-2 in this study. However only C-band data of the SAR image was used. The work can be improved with help of processing and analyzing SAR data of the same area with varying wavelength bands such as L band and C-band with same incidence angle on this study area.

**Acknowledgement:**
The authors are grateful to The European Space Agency (ESA), Norway and Institute of Remote Sensing (IRS), College of Engineering, Guindy, India.

**References:**