Change Detection on SAR Images

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***Abstract*—Change detection in multi-temporal Synthetic Aperture Radar (SAR) images has drawn an increasing attention due to the weather and illumination-independent characteristics of SAR and to the availability of satellite SAR images with medium or high resolutions. Classification of land cover classes into changed and unchanged class is very important in SAR change detection. SAR image change detection is limited by the inherent noise present in SAR images known as speckle noise so reduction of speckle comes in the pre-processing part of SAR data analysis. Ratio operators like mean and log ratio operators can be used to obtain the change detection map from pre-processed SAR images. This paper assesses the effectiveness of ratio operators with wavelet based technique for SAR change detection. Multi-temporal SAR images of Madurai city of the period 2015 and 2016 from SENTINEL-1 space borne SAR mission are taken as inputs. Among different standards wavelets, Gabor wavelet is used as the feature extraction tool due to its analyzation with different kernel sizes, scales and orientations. Based on the texture features extracted from the log and mean ratio difference images, the land features are classified into changed and unchanged classes using unsupervised fuzzy *c*-means (FCM) clustering.**

Index Terms*— Synthetic Aperture Radar (SAR), Gabor wavelet, change detection, fuzzy c-means (FCM) algorithm.

I. INTRODUCTION

Change detection using remote sensing is a process that analyzes two or more remote sensing images acquired over the same geographical area at different times to find changes that may have occurred between their acquisition dates. In the last decades, it has attracted widespread interest because of its large number of applications in diverse disciplines such as positioning and hazard assessment of earthquake, monitoring of crop growth conditions, detection of urban land use, medical diagnosis, and video surveillance. With the development of remote sensing technology, change detection in remote sensing images becomes more and more important. Among them, change detection in Synthetic Aperture Radar (SAR) images exhibits some more difficulties than optical images due to the fact that SAR images suffer from the presence of the speckle noise. However, synthetic aperture radar (SAR) is active microwave coherent imaging radar, so it can acquire remote sensing data under all weather and all day, which can make the change detection in SAR images still attractive.

From the literature survey it is clear that change detection in SAR images can be divided into three stages: 1) image pre-processing; 2) producing difference image between the multi-temporal images; 3) analysis of the difference image. In the first stage following tasks are included namely co-registration, geometric corrections, and noise reduction. In the second stage, to generate difference image two co-registered images are compared pixel by pixel. Differencing (Subtraction operator) and rationing (Ratio operator) are well-known techniques to obtain difference image from the remote sensing images. In subtraction operator, by subtracting the intensity values pixel by pixel between the considered couple of temporal images changes are measured. In rationing, changes are obtained by applying a pixel-by-pixel ratio operator to the considered couple of temporal images. However, in the case of SAR images, the ratio operator is typically used instead of the subtraction operator since the image differencing technique is not adapted to the statistics of SAR images and non robust to calibration errors [5]. Because of the multiplicative nature of speckles in the SAR images, the ratio image is usually expressed in a logarithmic or a mean scale [8]. In the third stage, SAR images are analyzed using various unsupervised change detection techniques like statistical similarity measure [1], thresholding [6], clustering [7], active contours [12], and Markov fusion [14], etc. Among them, the clustering methods are a simple yet effective family, being popular and well accepted in the SAR community. Clustering is a process of grouping a given collection of unlabeled patterns (observations or feature vectors) into meaningful clusters. Unsupervised change detection is to directly analyze the multi-temporal source images or their derivatives to discriminate the unchanged and changed classes without requiring any ground reference.

In general, it appears clearly from the literature that the whole performance of SAR image change detection is mainly relied on the quality of the difference image and the accuracy of the classification method. In order to address the two issues, in thi paper, we propose an unsupervised SAR image change detection approach with Gabor feature extraction and Fuzzy *c*-means clustering (FCM). The problem in Classical set theory/hard classification decision rule (pixel belongs to one class only) is that the boundaries between geographical entities are often imprecise, and/or there is heterogeneity within a texture in one class that causes spectral overlap with texture in other classes. K-means clustering is belongs to hard classification technique, so it cannot handle data points that are close to more than one cluster. Using fuzzy logic the above problem can be overcome. One possible fuzzy clustering is use of fuzzy *c*-means clustering.

The rest of this paper is summarized as follows; the proposed work is described in section II, results and discussion is described in section III, and concluded in section IV.

II. PROPOSED WORK

This paper uses ratio operator and wavelet based feature extraction for change detection from two SAR images acquired at different times. Multi-temporal image data set for Madurai july,2015 and july,2016 taken from Sentinel-1 are used as the input to the system. Unsupervised classification is done by fuzzy *c*-means method to obtain change detection map. The proposed work is shown in Figure1.

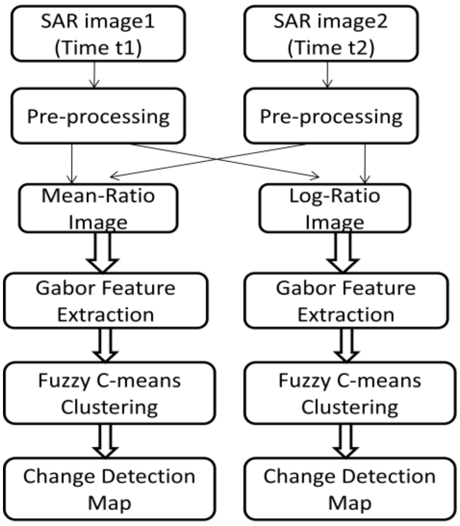

Figure.1: Block Diagram of the Proposed work

A. *Study Area*

In this paper the study area chosen is Madurai. An 8*8 km area including the city is taken as the study area, different earth surface features in the specified area are classified into two classes (changed and unchanged). The study area covers various earth features such as urban, vegetation, water body and wasteland. This study uses Ground Range Detected (GRD) product of processing level-1. Sentinel-1A takes images with a temporal interval of 12 days. Such images from July,2015 and July,2016 have been taken as input data for SAR change detection. All the input images are captured in interferometric wide swath (IW) mode and they are further focused and ground range detection is performed to form a product with a resolution of 20*22m (range*azimuth) and with a pixel spacing of 10*10m.

B. *Pre-processing- Speckle Noise Removal*

Pre-processing steps are also different from the pre-processing applied for optical images. SAR data products requires various levels of processing according to the product taken. De-bursting of multiple swaths, terrain correction, ground range detection, focusing, speckle removal etc. are some of the general processing methods. This project takes a level-1 processed ground range detected product which is focused and multi-looked already. So here pre-processing indicates mainly the reduction of speckle from the image. The grainy "salt and pepper" appearance of a SAR image results from constructive and destructive interference of the coherent SAR pulse by different scatterers contained within a resolution cell. Since speckle is a type of salt and pepper noise of random nature, it can be reduced by lee filter. Lee filter can preserve edge details in low as well as in high contrast hence it has adaptive nature. In this paper for July, 2015 and July, 2016 SAR input images lee filtering process is done using ESA Next Generation SAR Tool Box (NEST) version 5.1 C to reduce the effect of speckle noise with window size 3*3.

C. *Ratio operators*

This paper uses different ratio operators to obtain change detection map from pre-processed two input SAR images acquired at different times. For this paper log ratio and mean ratio operators are used to obtain the difference image. These two ratio operators are explained below.

1) Log Ratio Operator: SAR change detection can be performed by using Log Ratio Operator. With the log ratio operator, the multiplicative speckle noise can be transformed into an additive noise component. The logarithmic operator is characterized by enhancing the low intensity pixels while weakening the pixels in the areas of high intensity. Therefore the distribution of two classes (changed & unchanged) could be made more symmetrical.

Log ratio operator is given by

$$X_t = \left| log\left(\frac{X2}{X1}\right) \right| = |log(X2) - log(X1)|$$

Where X1 & X2 are two different SAR images taken at different times.

2) Mean Ratio Operator: SAR change detection can also be performed by using Mean ratio operator. Mean ratio operator is robust to speckle noise. Change in the scene will appear as a modification of the local mean value of the image. Emphasize the differences in the low intensities of the temporal images. The underlying idea of the optimal difference image is that unchanged pixels exhibit small values, whereas changed areas exhibit larger values. It shows changed region but it doesn't enhance it.

Mean Ratio Operator is given by

$$X(i,j) = 1 - min\left(\frac{\mu_1(i,j)}{\mu_2(i,j)}, \frac{\mu_2(i,j)}{\mu_1(i,j)}\right)$$

Where µ1(i, j) and µ2(i, j) represent the local mean values of the pixels involved in a neighbourhood of point (i, j) in X1 and X2, respectively.

D. *Wavelet Based Feature Extraction*

This paper uses Gabor wavelet tool to extract texture features from log ratio and mean ratio SAR images. Wavelet is applied with different scales and orientations to obtain the optimal change detection output from the clustering algorithm. Simple fuzzy clustering on the input log ratio and mean ratio SAR images produced very poor change detection output. This motivates the use of feature vectors of log and mean ratio SAR images obtained from Gabor wavelet for clustering the image into changed and unchanged regions.

A 2D Gabor function g(x, y) and its Fourier transform G(u, v) can be written as:

$$g(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} exp\left[\frac{-1}{2}\left[\frac{x^2}{\sigma_x{}^2} + \frac{y^2}{\sigma_y{}^2}\right] + 2\pi j w_x\right]$$

$$G(u,v) = \frac{1}{2\pi\sigma_x\sigma_y} exp\left[\frac{-1}{2}\left[\frac{(u-w)^2}{\sigma_u{}^2} + \frac{v^2}{\sigma_v{}^2}\right]\right]$$

Where, $\sigma_u = \frac{1}{2\pi\sigma_x}$, $\sigma_v = \frac{1}{2\pi\sigma_y}$

$$x' = a^{-m}(xcos\theta + ysin\theta)$$

$$y' = a^{-m}(-xsin\theta + ycos\theta)$$

Where, $\theta = \frac{n\pi}{k}$

Let k is the total number of orientations.

Gabor wavelet is an advanced wavelet tool which gives more freedom of tuning the wavelet. Different scales and orientations are possible for Gabor wavelets, also various kernel sizes can be chosen. In this study first experiment was to find the optimum kernel size which extracts features without much loss of information. On the analysis a 4*4 kernel served better feature extraction output. The next step was on finding the right scale and orientation for Gabor wavelet. Different scales and orientations are evaluated for clustered output accuracy, the results which produced better outputs.

E. Unsupervised Classification Techniques

The output from the texture feature extraction is a set of images. These images are feature images that will form the basis for the classification. Change detection classification is performed based on the feature vectors.

The *k*-means and fuzzy *c*-means clustering techniques, the most used unsupervised algorithms are used to classify the feature vectors obtained from gabor feature extraction into changed and unchanged classes. In this paper fuzzy *c*-means clustering is applied for extracted feature vectors of log and mean ratio SAR images from gabor wavelet to obtain SAR change detection map.

1)Steps involved in fuzzy c-means

Main objective of fuzzy *c*-means algorithm is to minimize

$$J(U,V)=\sum_{i=1}^{n}\sum_{j=1}^{c}(\mu_{ij})^m\left\|x_i-v_j\right\|^2$$

Let X={x1,x2,x3,……,xn} be the set of data points and V={v1,v2,v3,……,vc} be the set of centers.

Randomly select ‘c’ cluster centers.

Calculate the fuzzy membership ‘μ_{ij}’ using:

$$\mu_{ij}=\frac{1}{\sum_{k=1}^{c}\left(\frac{d_{ij}}{d_{ik}}\right)^{\frac{2}{m-1}}}$$

Compute the fuzzy centers ‘v_j' using:

$$v_j=\frac{\sum_{i=1}^{n}(\mu_{ij})^m x_i}{\sum_{i=1}^{n}(\mu_{ij})^m}\quad,\quad \forall j=1,2,\ldots.c$$

Repeat the steps until the minimum ‘J’ value is achieved or $\left\|U^{k+1}-U^{k}\right\|<\beta$

Where, ‘k’ is the iteration step.

‘β’ is the termination criterion between [0,1].

‘$U=(\mu_{ij})_{n*c}$’ is the fuzzy membership matrix.

‘J’ is the objective function.

F. Accuracy Assessment

The quantitative analysis of change detection results is set as follow. First, we calculate the false negatives (FN, changed pixels that undetected). Second, we calculate the false positives (FP, unchanged pixels wrongly classified as changed). Third, we calculate the percentage correct classification (PCC). It is given by

PCC = (TP+TN)/(TP+FP+TN+FN)

Here, TP is short for true positives, which is the number of pixels that are detected as the changed area in both the reference image and the result. TN is short for true negatives, which is the number of pixels that are detected as the unchanged area in both the reference image and the result.

III. RESULTS AND DISCUSSION

A. Input Images

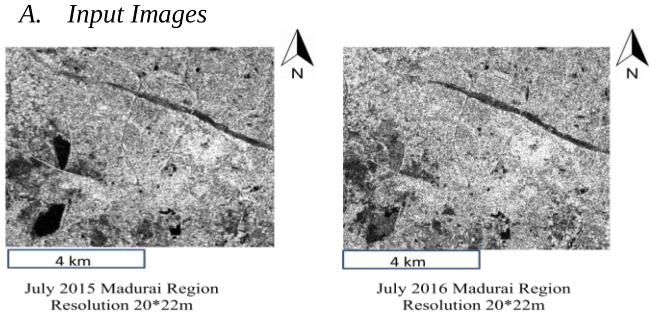

Figure.2: SAR Input Images

B. *Pre-processed images*

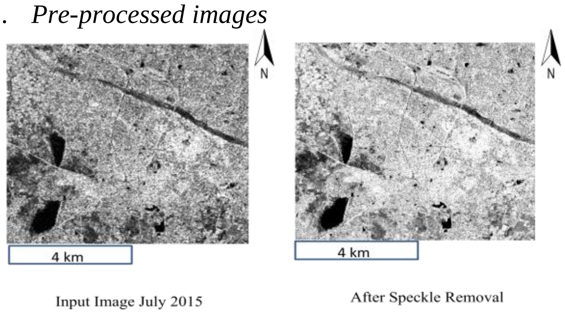

Figure.3: Pre-processed July 2015 SAR image

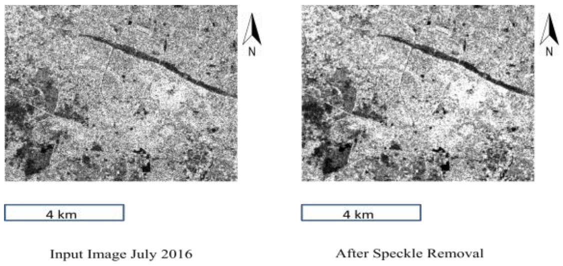

Figure.4: Pre-processed July 2016 SAR image

C. *Mean and Log Ratio Images*

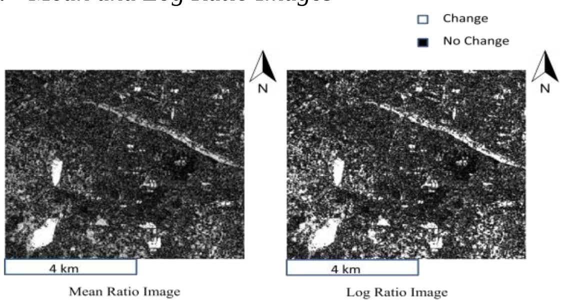

Figure.5: Different SAR images from Mean & Log Ratio Operator

D. *Classified Output*

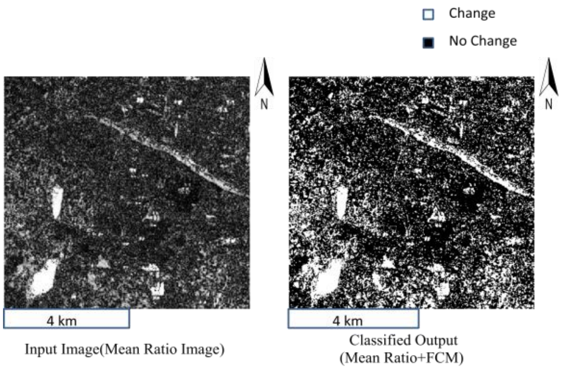

Figure.6: Input and FCM Classified Images

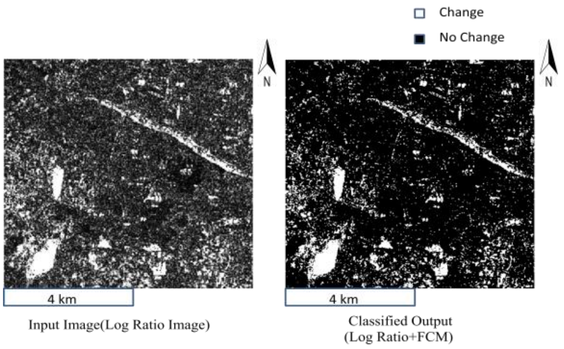

Figure.7: Input and FCM Classified Images

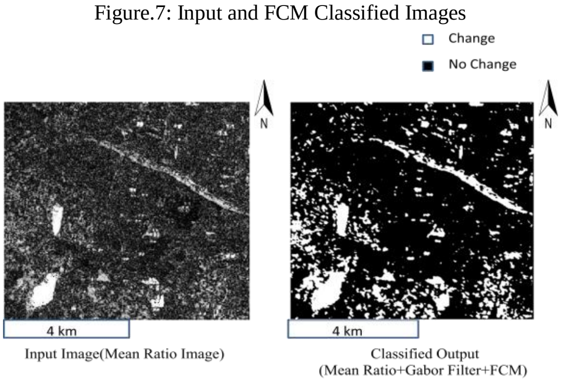

Figure.8: Input and FCM Classified Images

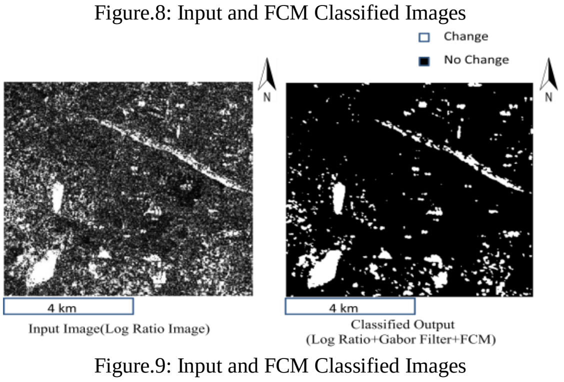

Figure.9: Input and FCM Classified Images

TABLE I. UNSUPERVISED SAR CHANGE DETECTION RESULTS OF THE MADURAI SAR DATA SET

Difference Image	FP	FN	TP	TN	PCC (%)
Mean Ratio + FCM	47	1	28	24	52
Log Ratio + FCM	37	2	34	27	61
Mean Ratio + Gabor Filter + FCM	26	2	44	28	72
Log Ratio + Gabor Filter + FCM	14	3	60	23	83

IV. CONCLUSION

The aim of this paper is to identify the changes for two SAR images taken at different times for the Madurai region. The two SAR images used are captured by SENTINEL-1A European SAR satellite in Interferometric Wide Swath (IW) mode of GRD (Ground Range Detected) type level-1 processed. The study area contains various land features in the scene. Algorithms are evaluated for 8*8 km area which covers main city and outskirts of the city. Ratio operators like mean ratio operator and log ratio operator are used with Gabor feature extraction technique to obtain the SAR change detection map from which changed and unchanged regions are observed. From the results obtained log ratio difference image with Gabor wavelet of 3 scales and 8 orientations of 4*4 kernel size resulted in the maximum accuracy of 83% (PCC) compared to mean ratio difference image Gabor wavelet of 3 scales and 8 orientations of 4*4 kernel size. The accuracy essentially proves the applicability of ratio operators with Gabor wavelet based feature extraction technique for SAR change detection. Finally this study concludes that ratio operator with Gabor wavelet can be effectively applied for SAR change detection. And also gives motivation to improve the algorithm so that the better accuracy can be achieved.

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