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Synthetic Aperture Radar (SAR) images features clustering using Fuzzy c-means (FCM) clustering algorithm

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Received 25 Jun 2012; *Accepted 29 July 2012*; *Published online 1 December 2012*
IAEES

Abstract
Remote sensing applications such as Ecological monitoring, Disaster monitoring, Volcanic monitoring, surveillance and reconnaissance requires broad range imaginary data with very high resolution. Data captured under different times such as day or night and under different weather conditions poses adverse affects on retrieved results. Synthetic Aperture Radar (SAR) technology is used to mitigate such adverse effects. Recently SAR technology re-emerges because of the decrease in the cost of electronic components and tremendous advancement in computing power. This paper provides an application of Fuzzy c-means (FCM) clustering algorithm to SAR Images. The objective of this study is to segment various region of interest in remote sensing images for ecological monitoring.

Keywords Synthetic Aperture Radar (SAR); Fuzzy c-means (FCM) clustering algorithm; satellite radar image; remote sensing; ecological monitoring.

1 Introduction

Synthetic Aperture Radar systems exploit long range propagation characteristics of radar signal and complicated data processing capability of digital electronics to get fine tune image (Lopez, 2012). A typical radar transmits and receives pulses at microwave wavelengths (corresponds to frequency range of 300 MHz to 30 GHz). These radar pulses are polarized in vertical and horizontal plane. Radar ranges and detects remote surface or object by measuring the strength and round-trip time of the microwave signal, transmitted from its antenna and reflected from remote surface or object (Ioannis and Meliadis, 2011; Knorr et al., 2011). Pulse round-trip time is used to determine the distance or the range of the object and the pulse width of the transmitted signal determines the resolution of the target image. Finer image can be obtained by increasing the bandwidth of the pulse. For Image radar systems, 10,000 high power pulses with pulse-width of 10 to 50 microseconds are used to get surface or object images. The energy of the pulses becomes weak once these pulses are reflected from the target surface. The received pulses are then stored and processed as a radar image (Ellen O'Leary, 2012).

Synthetic Aperture Radar (SAR) is a form of radar with sophisticated post processing of received data. It synthesize very long antenna by receiving the echo pulses as the flight move across the target-track, while the aperture of the radar involves the collection of the backscattered waves of the target. Thus SAR process involves the collection of echo from the target image while transmit and receive antenna is moving across the target. The length of the track of the radar that covers the target area determines the resolution of image and is referred as azimuth. The longer the antenna size the better is the resolution.

As the radar moves relative to the ground, the received pulses are Doppler shifted: positively as it move away and negatively as it approaches towards the target. These Doppler shifted frequencies should be well addressed in order to precisely sense the remote object. A number of algorithms have been proposed to address this issue.

The polarized nature of Radar waves make it possible to detect surface changes of certain material including vegetation or soil moisture. Radar antenna receiver and transmitter involve three different configurations of polarizations which are HH-pol, VV-pol and VH-pols. These configurations are used to represent three colors in synthesis image. Number of studies has been performed using polarization technique, including (Hashim et al., 1999) for rain forest mapping. (Barotani et al., 1995) presents SAR Polarmetric features for agricultural monitoring.

Chirp or pulse compressed signal is widely used in SAR systems. The pulse width in chirp radar is much longer due to which it emits more energy but usually hinder range resolution. Longer pulse width also results in frequency shift, so the chirped short signal is correlated with the transmitted pulse on its reception. Moreira and Huang (1994) used Chirp scaling algorithm for high resolution processing of SAR data with high squint angle and motion error.

In this paper we will discuss the application of FCM Algorithm for SAR System applications for remote sensing. A brief description of specialized SAR technique termed as Differential Radar Interferometry (DInSAR) is presented in section 2. In section 3, FCM Algorithm applied on SAR Image. The paper is concluded in Section V with future research directions.

2 SAR Interferometry

2.1 Defination

Synthetic Aperture Radar (SAR) systems record both amplitude and phase of the backscattered echoes. The phase of the backscattered echoes represents each pixel of the image and is comprised of the following three components (Rocca and Prati, 2012):

1) Two way travel path from radar antenna to target and from target back to radar antenna.
2) Interaction between the incident and scattered electromagnetic waves.
3) The phase shift induced by the processing system used to focus the image.

Single SAR image phase has no practical value. Two SAR images taken from slightly different angles are termed as Interferometric pair and their phase difference is termed as Interferometric fringes. The phases of Interferometric pair can be used to develop Digital Elevation Maps (DEM’s).

2.2 Limitations of DInSAR

DInSAR has some limitations which adversely affects the accuracy of the system. One such limitation is due to the fact that satellite platform do not follows an ideal trajectory. This inaccuracy should be well addressed to maintain the reliability of the system, and it is termed as Motion Compensation (MoCo).

Another form of inaccuracy is termed as Residual Motion Error (RME’s). This type of inaccuracy is the result of measurement error due to antenna position, which is in the order of 1-5 cm. In order to address Motion Compensation and Residual Motion Error in topological variation, number of algorithms has been used. Some examples are Frequency Division algorithm, Topography and Aperture Dependant (TAD) algorithm, Sub Topography Aperture Dependant (SATA) algorithm (de Macedo and Scheiber, 2005).

2.3 SAR processing scaling algorithms

The idea behind scaling technique is to improve the accuracy of the phase of complex image, without using interpolation to rectify Range Cell Migration. A number of algorithms have been used for data processing which includes Chirp Scaling Algorithm (CSA), Frequency Scaling Algorithm (FSA) and Extended Frequency Scaling Algorithm (EFSA) has been proposed (Zhou et al., 2008).

One of the limitations of Chirp Scaling Algorithm is that it cannot be directly applied to dechirp SAR processing data. Range Cell Migration (RCM) trajectory corresponds to the frequency of range signal. Frequency Scaling Algorithm (FSA) is similar to Chirp Scaling Algorithm as it does not require interpolation. Another improved algorithm proposed by (Gabriel et al., 1989) is Extended Frequency Scaling Algorithm (EFSA), which is particularly important in case of squint image geometry. This scaling algorithm is an attempt to improve FSA, because FSA has high sampling rate and larger storage array for a range of spectrum shift which cause adverse effects on processing of squinted data.

3 Fuzzy Cluster Mapping Applied on SAR Image

Fuzzy c-means (FCM) clustering algorithm (Dunn, 1974; Cannon et al., 1986) had widely been used for clustering various data set including data related with satellite images (HTTP://WWW.JPL.NASA.GOV/RADAR/SIRCXSAR/ISABELA.HTM) . This study is an attempt to further explore the famous FCM algorithm for SAR Images. The particular interest here is to monitor the certain features of the satellite image for the object of interest. For example displacement of ice sheets, land sliding, avalanche and various other parameters can be evaluated for different environmental conditions.

FCM analysis on various images is shown in Figs 1-4. Fig. 1(a) is original SAR image [image source], which is used for various experimental setups. Fig. 1(b) and Fig. 1(c) shows visual results of different set of FCM using class 2. This class has low computational complexity (number of iteration and execution time) and can be used as a bench mark for classes with higher orders. Fig. 2(a) Fig. 2(b) and Fig. 2(c) shows visual results of different set of FCM using class 3. Fig. 3(a) Fig. 3(b) and Fig. 3(c) shows visual results of different set of FCM using class 4.

Fig. 4 and Table 1 shows the computational complexities of three classes used in this analysis. In class 2, initially 4840 clusters obtains which reduces stabilize to 1651 clusters after seventh iterations. In class 3, initially 3407 clusters obtains which reduces stabilize to 1042 clusters after seventh iterations. In class 4, initially 2588 clusters obtains which reduces stabilize to 808 clusters after seventh iterations. When we used FCM class 4 for the SAR image, better clustering results obtain at the cost of higher computational complexity as shown in Fig. 4 and Table1.

(a) (b) (c)

Fig. 1 Visual results of different set of FCM Algorithm (Dunn, 1974) and (Bezdek et al., 1986) (using class 2 clustering)

(a) (b) (c)

Fig. 2 Visual results of different set of FCM Algorithm (Dunn, 1974) and (Cannon et al., 1986) (using class 3 clustering)

(a) (b) (c)

Fig. 3 Visual results of different set of FCM Algorithm (Dunn, 1974) and (Cannon et al., 1986) (using class 4 clustering)

Table 1 Clustering results by using FCM algorithm (Dunn, 1974) and (Cannon et.al., 1986). The class 2 with low computational complexity (number of iteration and execution time) and can be used as a bench mark for classes with higher orders class 3 and class 4.

Iterations	FCM-2	FCM-3	FCM-4
1	4840.115769	3407.017055	2588.334206
2	3950.785278	2633.972645	1975.481975
3	3947.538858	2632.979852	1974.759551
4	3911.997359	2622.011220	1966.795816
5	3582.060563	2511.201795	1887.523555
6	2358.339693	1895.002310	1463.581625
7	1651.986414	1042.747151	808.761810
8	1574.110134	670.480402	511.689643
9	1564.096868	649.178093	491.169070
10	1562.239961	648.080386	486.621747
11	1561.886933	647.814928	466.213148
12	1561.820750	647.686897	411.614598
13	1561.808448	647.615841	377.924829

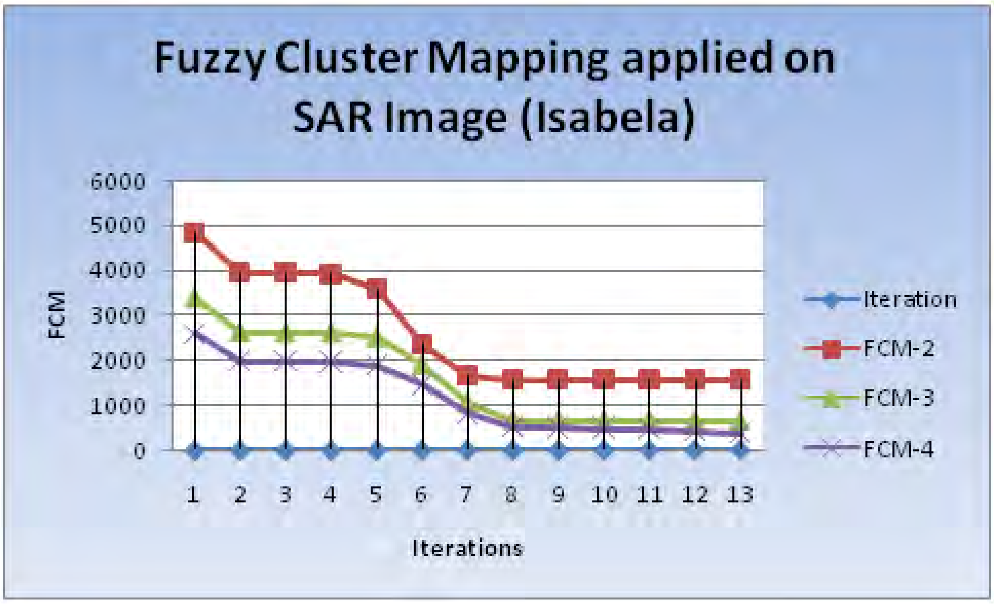

Fig. 4 Show the clustering results by using improved FCM algorithm (Dunn, 1974) and (Cannon et.al., 1986). Higher clustering performance obtains using class 4 (FCM-4). Lower clustering performance obtains using class 2 (FCM-2).

4 Conclusion

Synthetic Aperture Radar (SAR) has become popular in recent years; it covers wide range of military and civilian remote sensing applications. This paper is an attempt to introduce Synthetic Aperture Radar technology with particular emphasis on feature clustering using FCM algorithm. This technology is important for long term monitoring and assessment of remote and hard to reach areas such as glaciers and volcanoes. Some of the research challenges are measuring target motion compensation, ground moving target imaging and three dimensional SAR image processing.

Acknowledgments

We wish to thank Matthew R. Lopez from Sandia National Laboratories Albuquerque, NM, USA, Ellen O'Leary from Radar Data Center, Jet Propulsion Laboratory Pasadena, CA for facilitating theoretical concepts, and to the Graduate School of Engineering Sciences and Information Technology, Hamdard University for their logistic support and services. Images were sourced from http://www.jpl.nasa.gov/radar/sircxsar/isabela.htm (Last visit: June 18, 2012)

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