A New Approach to Ship Detection based on Synthetic Aperture Radar Data

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Abstract

MLCC (Multi-Look Cross-Correlation) is a useful technique to extract the images of ships embedded in sea clutter from SAR (Synthetic Aperture Radar) data[1]. However, the previous MLCC has a difficulty of detecting small ships since SNR (Signal-to-Noise Ratio) is not high enough. Therefore, we developed a new Improved MLCC (IMLCC) to increase SNR to extract small boats. Although the LMLCC method increased SNR, there still remained some highly correlated noises in the coherence images caused by strong radar backscatter from sea surface. In order to improve the IMLCC algorithm further, we propose a new method of applying Lognormal-CFAR (Constant False Alarm Rate) to IMLCC coherence images. The results using ALOS-PALSAR (Advanced Land Observing Satellite-Phased Array L-band SAR) data showed substantial improvement in SNR and detection rate.

Keywords : Synthetic aperture radar SAR PALSAR ship detection AIS.

1. Introduction

In recent years, ship detection by synthetic aperture radar (SAR) has attracted much attention for monitoring traffic, fishing activity, and increasing illegal maritime crimes, and substantial number of experimental and theoretical studies have been reported.

Since the launch of Advanced Land Observing Satellite (ALOS) in 2006, we have been developing a ship detection system using PALSAR on board of ALOS. One of the algorithms we focused on is the multi-look cross-correlation technique (MLCC), yielding improvement in detection accuracy[2]. However, the previous MLCC could not detect small ships very well since SNR and the detection rate are also not high enough. Therefore, to increase the SNR and detection rate of MLCC, we propose, in this paper, a method of IMLCC and Lognormal-CFAR.

We conducted experiments in Tokyo Bay in order to develop an integrated ship detection and identification system with SAR, ground-based maritime radar with automatic identification system (AIS). In this paper, we will report our result of ship detection experiment in the Tokyo Bay using PALSAR data.

2. SAR and Meteorological data

The data we used in the experiments are ALOS-PALSAR FBS 34.3 data (Fine Beam Single mode at off-nadir angle 34.3 degrees) acquired at 01:10 - 01:20(UT) on the 18th December 2008 and 16th January 2009. The spatial resolution cells are 4.1 m in azimuth direction and 7.2 m in range direction. Fig.1 shows the test site in the white square and the ground-based radar site from, which visual observation was also made. According to the meteorological data obtained at a station close to the experimental site, the sea was calm with significant wave height 0.26 m and 0.27 m, and wind speed 2.0 m/s and 2.0 m/s at the time of PALSAR observation in 2008 and 2009 respectively.

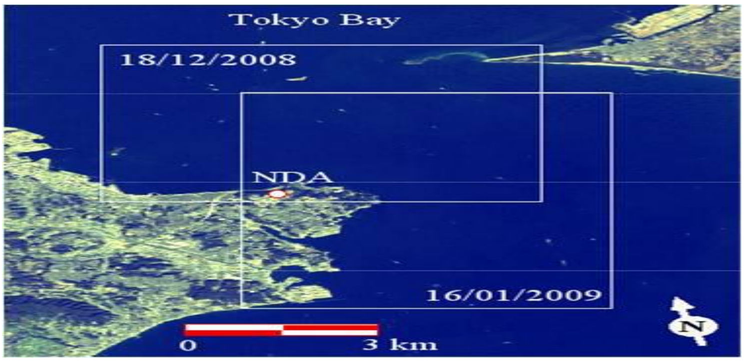


Fig.1 AVNIR-2 image indication the test areas by white squares. The different test area in the 2008 and 2009 data are due to different visual observation sites. The AIS is located at NDA (white circle)

3. Methodology

The MLCC and IMLCC is defined as

$$C_{MLCC} = \frac{\langle A_1 A_2 \rangle}{\langle A_1 \rangle \langle A_2 \rangle} - 1 \tag{1}$$

where A_j is the look j image amplitude, and the angular brackets indicate taking an ensemble average.

$$C_{IMLCC}(i, j) = \sum_{m=1}^{M} \sum_{n=1}^{N} A(m,n) \cdot B(m+i, n+j)^* \tag{2}$$

where M and N are window size, $A\,(m\,,n)$ and $B\,(m+i\,,n+j)$ are the look-1 and look-2 amplitude images respectively and * indicates taking complex conjugate.

Because the center frequencies of sub-apertures are separated in such a way that the sub-apertures do not overlap, the speckle patterns arising from background ocean surface are not correlated between looks. While the deterministic images of ships have strong inter-look correlation. In the conventional MLCC algorithm, the cross- correlation value is taken from the center of the cross-correlation function within a moving window. However, if the ships are moving, the images are produced at different positions in the sub-images. This is indeed the basis of velocity vector estimation of moving targets[3]. For ship detection, however, the peak value of the inter-look cross-correlation is different from the center of the axis of the window because the image positions of moving ships are different between looks. Thus, to optimize the MLCC algorithm, the maximum cross-correlation value is sought within the window as in equation (2). This is IMLCC.

Table 1 shows the Peak to Background Noise Ratio (PBNR) in dB unit for the images of ships present in the test site in 2008 and 2009. The average PBNRs over all detected ship' image in both the 2008 and 2009 data were 2.27 dB, 2.34 dB, and 4.32 dB in amplitude image, MLCC coherence image, and IMLCC coherence image respectively. The total of 37 and 20 ships corresponding to the 2008 and 2009 data respectively were confirmed by AVNIR-2, AIS, and visual observation using video camera, which were considered as the "true" number of ships. Figure 2 shows that the numbers of detected ships were 23, 23 and 33 by the amplitude, MLCC and IMLCC respectively in 2008. In 2009, the corresponding numbers were 11, 10 and 18. The white circles correspond to the ships without AIS and their signals, whose positions were confirmed by the AVNIR-2 images and visual observation from ground by a video camera. The white triangles indicate the ships without AIS signals, located outside the video camera sight, but detected by the AVNIR-2. From these results, our report shows that the IMLCC performed best, followed by MLCC and amplitude-based methods.

Table 1 : Average Peak to Background Noise Ratio (PBNR) in dB unit for the images of ships shown in Figure 2 and the numbers inside the brackets show the number of detected ships.

No	Amplitude image	MLCC coherence image	Improved MLCC coherence image
2008	1.38 (23)	1.48 (23)	4.50 (33)
2009	3.15 (11)	3.20 (10)	4.13 (18)

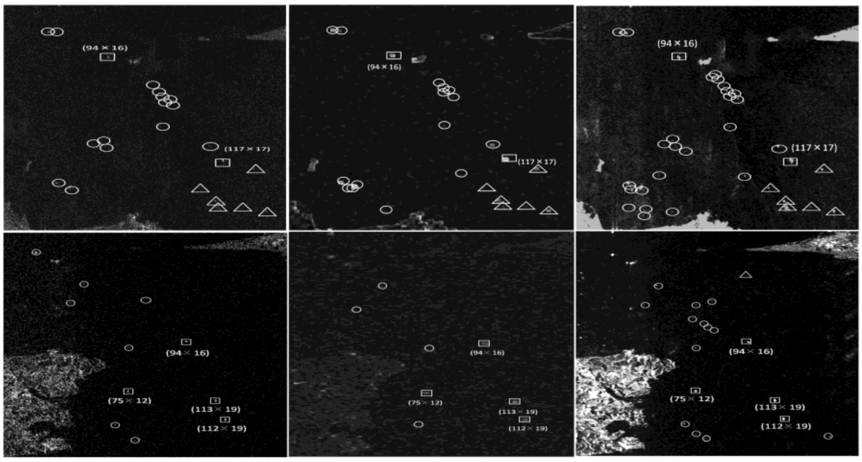


Fig.2 Amplitude image (left), MLCC coherence image (middle) and IMLCC coherence image (right). The upper and lower rows correspond respectively to the 2008 and 2009 data. The range and azimuth directions are from right to left and top to bottom respectively

4. Lognormal CFAR Technique

The study about ship detection can now be advanced a step further to extract appropriate threshold. For this purpose, we adopted constant false alarm rate (CFAR) theory to the IMLCC coherence images. In order to apply CFAR to the coherence image from IMLCC, it is necessary to find a best fitted Probability Density Function (PDF). In this study, we considered 4 distribution models including Lognormal, Gamma, Weibull and Rayleigh distribution. After a best fitted distribution is confirmed, the next step is to determine parameters for estimated PDF by Maximum Likelihood Estimation (MLE) and calculating a threshold value by numerical integration. In this step, we used moving window whose size is 100×100 within the entire IMLCC coherence image and the threshold value T is derived from

$$1\text{-}\mathrm{FAR} = \int_0^T f(H)\,dH \tag{2}$$

where f is the PDF, H means pixel value of moving window and FAR is the false alarm rate. We set a FAR value as 1.0E-04. In this stage, when a certain threshold value is less than the mean pixel value of the whole image, we set a value of moving window to zero. For this reason, we detected ships very effectively and it was able to remove noise.

Figure 3 shows the PDF which fits best to the coherence images in 2008 (left) and 2009 (right) data. The best fit was Lognormal distribution (location parameter : 1.12, -1.14 and scale parameter : 0.27, 0.19), followed by gamma distribution (shape parameter : 13.31, 25.6 and scale parameter : 0.24, 0.12),Weibull distribution (order parameter : 0.35,0.35 and shape parameter : 3.54, 4.56) and Rayleigh distribution (shape parameter : 2.36, 0.23). The first and second numbers in the brackets mean the data in 2008 and 2009 respectively. Figure 4 shows the results of Lognormal CFAR. The detection rate for the images of ships present in the test site decreased from 94 % in IMLCC to 83 % in Lognormal CFAR but PBNR improved from 4.31dB in IMLCC to 6.27dB in Lognormal CFAR respectively.

5. Conclusions

A technique of MLCC is known to be able to extract the images of ships embedded in clutter by thresholding coherence images produced by cross-correlating sub-aperture SAR images.

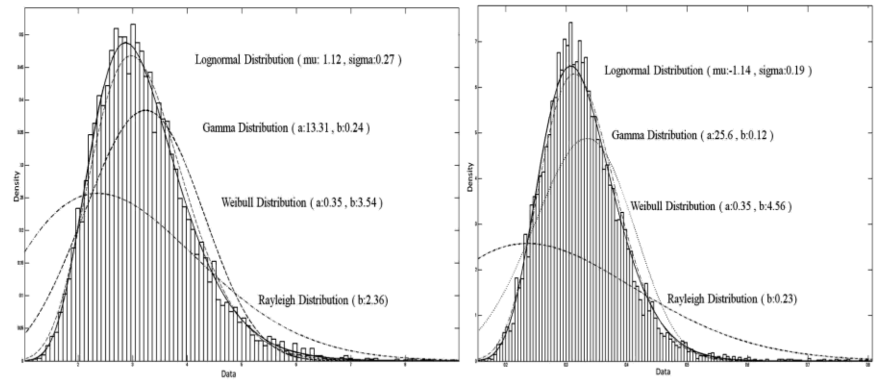
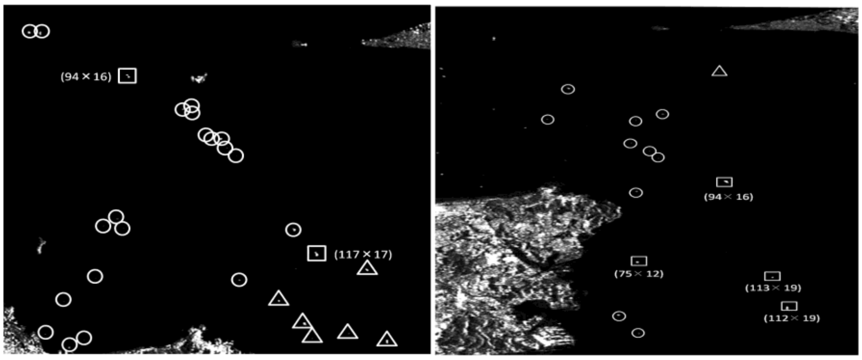


Fig.3 PDF of Improved MLCC coherence images. The left is the result of 2008 data. (range pixels :1401 to 1500 and azimuth pixels : 3301:3400), and the right is result of 2009 data. (range pixels :1501 to 1600 and azimuth pixels : 1601:1700)



Results of Lognormal CFAR (left:2008) and right:2009). The whole area of this images are computed by Lognormal CFAR and the land areas are masked using IMLCC coherence image

The basic idea is the strong inter-look correlation of deterministic targets such as ships, and weak correlation of surrounding noise. One of the problems of this method is that it has a difficulty of detecting small sips since SNR is not high enough. In the present study, we proposed a new simple algorithm of IMLCC to increase SNR and extract small boats, and also proposed Lognormal CAR to determine an appropriate threshold value for IMLCC coherence images. We tested the proposed method of IMLCC and Lognormal-CFAR using ALOS-PALSAR data containing small boats of sizes comparable with the SAR resolution cells. The results showed that substantial improvements were made by Improved MLCC and Lognormal-CFAR in both the PBNR and detection rate in comparison with amplitude images. The project is still in progress, and currently, we are analyzing other sets of PALSAR, RADARSAT-2, and also TerraSAR-X data over the same test site with simultaneous ground truth data. The results will be reported in the near future.

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