An efficient ship detection method for KOMPSAT-5 synthetic aperture radar imagery based on adaptive filtering approach

JeongIn Hwang, Daeseong Kim and Hyung-Sup Jung†
Department of Geoinformatics, University of Seoul

Abstract: Ship detection in synthetic aperture radar (SAR) imagery has long been an active research topic and has many applications. In this paper, we propose an efficient method for detecting ships from SAR imagery using filtering. This method exploits ship masking using a median filter that considers maximum ship sizes and detects ships from the reference image, to which a Non-Local means (NL-means) filter is applied for speckle de-noising and a differential image created from the difference between the reference image and the median filtered image. As the pixels of the ship in the SAR imagery have sufficiently higher values than the surrounding sea, the ship detection process is composed primarily of filtering based on this characteristic. The performance test for this method is validated using KOMPSAT-5 (Korea Multi-Purpose Satellite-5) SAR imagery. According to the accuracy assessment, the overall accuracy of the region that does not include land is 76.79%, and user accuracy is 71.31%. It is demonstrated that the proposed detection method is suitable to detect ships in SAR imagery and enables us to detect ships more easily and efficiently.

Key Words: ship detection, synthetic aperture radar (SAR), NL-means filter, median filter

1. Introduction

International interest in ship detection and its monitoring has been rising because it is related to environmental conservation, maritime safety, immigration, terrorism, organized crime, and military and defense issues (Khesali et al., 2015). Ship detection can be more efficiently carried out using a Synthetic Aperture Radar (SAR) technique rather than other remote sensing techniques because the SAR technique provides broad area information, has all-weather observation capabilities and high spatial resolution. It is possible to distinctly separate ships from the surrounding sea using SAR imagery because of corner reflection, which is multiple backscatter transmitted from a radar signal off of an artificial structure. However, the unique SAR imaging geometry and process also results in indistinct appearance of ships, image distortions and speckle noise.

Previous studies of ship detection are divided into...
three major approaches. In one approach, statistical distribution models are widely used to detect ships in SAR imagery (Hansen, 1973; Rohling, 1983; Armstrong and Griffiths, 1991; Alberola-López et al., 1991; Wang et al., 2008; Wang et al., 2016). Another approach relies on the information extracted by image spectral analysis, decomposition or wavelet transformation (Souyris et al., 2003; Ouchi et al., 2004) while other studies depend on SAR image-based feature extraction and selection (Kaplan et al., 2001; Howard et al., 1999).

In this paper, we propose an efficient, simple method to detect ships from high-resolution KOMPSAT-5 imagery using filtering techniques. The KOMPSAT-5 is a high-resolution X-band SAR satellite, and SAR imagery can be utilized successfully for ship detection. The proposed method has the advantage of being simpler than other previous studies. Next, we demonstrate that the proposed method can be successfully applied for ship detection in SAR imagery.

2. Study Area and Data

The study area is in the South Sea of Korea adjacent to Busan. This area includes two main ports, one is Busan Port and the other one is Busan New Port, which is located in Changwón, South Gyeongsang Province. There are many large vessels in this area, making it a good location to use for ship detection.

To detect ship targets in SAR imagery, we used KOMPSAT-5 data, which is Single Look Complex (SLC) level 1A data. The KOMPSAT-5 satellite was launched in 2013, with data collected by the X-band SAR sensor. Table 1 shows the characteristics of the SAR imagery used in this study. Additionally, to generate a simulated SAR intensity image and mask land areas, SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) data with 30 m resolution was used (Van Zyl, 2001; Werner, 2001; Farr et al., 2007).

### Table 1. Characteristics of KOMPSAT-5 SAR image used in this study

| Date          | July 27, 2016, 09:19:4.01 (UTC) |
|---------------|---------------------------------|
| Imaging mode  | Standard (Strip)                |
| Polarization  | HH                              |
| range pixel spacing | 1.2491 m            |
| incidence angle          | 39.9027 deg.             |
| grd. Range pixel spacing | 1.9317 m                |
| azimuth pixel spacing   | 1.9995 m                   |
| Path          | descending                     |

Mission Digital Elevation Model) data with 30 m resolution was used (Van Zyl, 2001; Werner, 2001; Farr et al., 2007).

3. Data Processing

A multilook operation was performed by averaging neighborhood pixels to the acquired KOMPSAT-5 SLC data. Five looks, in range and azimuth respectively, were applied to reduce the speckle noise in the SLC image and ground range and azimuth pixel spacing were converted to approximately 10 m. After attaining a SAR intensity image and converting the units of the intensity image to decibel (dB), land masking was then carried out using a simulated SAR intensity image from acquired SRTM DEM in the study area. However, the speckle noise remained in the land masked image. Thus, a Non-Local means (NL-means) filter was applied to mitigate the remaining speckle noise. Because the filter weighs how similar the center pixel and neighboring pixels are to each other, it preserves the boundary of the object but also effectively reduces the noise (Buades et al., 2005). We took a 5 by 5 size to each search and similarity window.

As mentioned above, in general, ships are observed as bright features in SAR imagery compared to the surrounding sea due to the corner reflection. Thus, in order to detect only the ships in the SAR image, we strategically excogitated the following ship detection method (Fig. 1). The tactics were 1) the masking out of
the ships in the NL-means filtered SAR image (reference image) using a median filter that considers the ship size, 2) the creation of a differential image from the difference between the median filtered image and the reference image, 3) the removing of outliers and statistical thresholding to the differential image and the reference image, 4) ship detection, accomplished by multiplying each of the two images. For median filter, we considered the size of the filter to minimize the false detection due to the remaining land areas that is not enough land masking and to maximize the ship detection. Empirically, the ideal window size of the median filter is \(21 \times 21\), which is approximately the maximum width of ship targets. For removing outliers and thresholding, when we used only differential image, we couldn’t find the clear threshold in the histogram and there are a number of false alarms. To solve this problem, we used two images, which are not only the differential image but also the reference image. Threshold was decided as a 95% value of the extracted samples from these two images.

4. Results

Fig. 2(a) is the SAR intensity image used as the input data for this study. Although speckle noise was reduced through applying multilook, it still remained and caused quality degradation. Fig. 2(b) shows the resultant image after a NL-means filter was applied to the original intensity image. In the NL-means filtered image, it was confirmed that the speckle noise was reduced while maintaining the resolution of the image. Fig. 2(c) shows the image with the median filter. The resolution is
reduced, but the candidate pixels of ships on the sea surface were removed. The white region labeled A in each of the images in Fig. 2 was selected to visually confirm changes before and after the filter application.
Fig. 3 is the extracted region A from each of the images including the original image, the NL-means filtered image and the median filtered image. In the original image, it can be seen that side lobe, speckle noise and ghosts phenomenon, that is the result from non-ideal antenna pattern and the finite pulse repetition frequency, all appear in the image (Fig. 3(a)). This noise was greatly reduced after applying the NL-means filter, and the contrast between the ships and the sea was further strengthened (Fig. 3(b)). In the image with the median filter, the ships were eliminated (Fig. 3(c)). To acquire the differential image, the median filtered image was subtracted from the NL-means filtered image.

As can be seen from the differential image, there are many pixels with high reflectance values besides the ships’ pixels (Fig. 4). The reason that land pixels were detected is based on the same principle that is used to detect the ships. It is caused by the effect of corner reflection off of high-rise buildings or by the mixing of different land types. In the case of the pixels detected in the ocean, these are mainly caused by the side lobe-effect and ghosts phenomenon.

To remove these outliers, a threshold were set by extracting samples from the NL-means filtered and differential images. As shown in Fig. 5, ships were detected using the threshold and land masking image.

Sites A, B, and C, marked with white rectangle in the figure, were selected to analyze the results.

Fig. 6(a) represents the false alarms from the side lobe effect and the DEM. Since the land masking was performed using SRTM DEM, landfills and bridges built since 2002 were not included. In addition, DEM was not generated for a number of sand bars. Therefore, some of the sand bars and a bridge were detected for this reason. Other false alarms were generated due to the ghost effect in the image as shown Fig. 6(b). Fig. 6(c) shows the false alarms that originated from the reclaimed land and a newly built bridge.

To validate this algorithm, the overall accuracy
and the user accuracy were calculated based on the Error Matrix presented in Table 2. The overall accuracy is the sum of the number of correctly identified pixels, divided by the total number of pixels. Moreover, the user accuracy is an index characterizing the amount of errors of omission. It is the number of the correctly identified pixels of a class, divided by the total number of pixels of the class in the classified image. Initially, the overall accuracy of the entire area was 72.75%, and user accuracy was 18.47%. The reason for poor user accuracy is due to the factors mentioned above. For validation of our proposed algorithm, the accuracy are calculated within region A in Fig. 7, which includes only ships without land. As a result, the overall accuracy of region A is 76.79%, and the user accuracy is 71.31%.

5. Conclusions

Ship detection in SAR imagery is a highly important issue by national demand, and many prior studies have treated with it. However, the previous studies used complicated approaches, such as statistical distribution models and complex image processing. In this paper, we proposed an efficient method to detect ships in KOMPSAT-5 SAR imagery. Our method was implemented using a median filtering approach. Because ships have much higher intensity values than the surrounding sea, the targets can be easily removed by means of a median filter. The measurement performance of the proposed ship detection method was carried out via visual inspection. There were also false alarms due to reasons such as the side lobe effect, a ghost effect in the SAR image, and land masking errors due to insufficient DEM information. According to the accuracy assessment, the overall accuracy of a region that does not include land is 76.79% and user accuracy is 71.31%. This result demonstrates that the proposed method is suitable to detect ships in SAR imagery.

Further study objectives include using the latest DEM for masking land, high quality satellite imagery, and a coherence map which has polarization information. Furthermore, we will analyze using machine learning or deep learning instead of a statistical threshold. This will lead to better ship detection results.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(NRF-2015M1A3 A3A04051025)
References

Armstrong, B., and H. Griffiths, 1991. CFAR detection of fluctuating targets in spatially correlated K-distributed clutter, *Proc. of F Radar Signal Processm IEEE*, 138(2): 139-152.

Alberola-López, C., J.R. Casar-Corredera, and G. de Miguel-Vela, 1999, Object CFAR detection in gamma-distributed textured-background images, *Proc. of Vision, Image and Signal Processing, IEE*, 146(3): 130-136.

Buades, A., B. Coll, and J.M. Morel, 2005. A non-local algorithm for image denoising, *Proc. of 2005 Computer Vision and Pattern Recognition, IEEE Computer Society Conference*, San Diego, CA, June 20-26, vol. 2, pp. 60-65.

Farr, T.G., P.A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodriguez, L. Roth, D. Seal, S. Shaffer, J. Shimada, J. Umland, M. Werner, M. Oskin, D. Burbank, and D. Alsdorf, 2007. The Shuttle Radar Topography Mission, *Reviews of Geophysics*, 45(2): RG2004.

Hansen, V., 1973. Constant false alarm rate processing in search radars, *Proc. of the Radar Present Future*, London, October 23-25, pp. 325-332.

Howard, D., S. Roberts, and R. Brankin, 1999. Target detection in SAR imagery by genetic programming, *Advances in Engineering Software*, 30(5): 303-311.

Kaplan, L.M., 2001. Improved SAR target detection via extended fractal features, *IEEE Transactions on Aerospace and Electronic Systems*, 37(2): 436-451.

Khesali, E., H. Enayatu, M. Modiri, and M.M Aref, 2015. Automatic ship detection in single-Pol-SAR Image using texture features in artificial neural networks, *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Science*, 40(1): 395-399.

Ouchi, K., S. Tamaki, H. Yaguchi, and M. Ichara, 2004. Ship detection based on coherence images derived from cross correlation of multilook SAR images, *IEEE Geoscience and Remote Sensing Letters*, 1(3): 184-187.

Rohling, H., 1983. Radar CFAR thresholding in clutter and multiple target situations, *IEEE Transactions on Aerospace and Electronic Systems*, 19(4): 608-621.

Souyris, J. C., C. Henry, and F. Adragna, 2003. On the use of complex SAR image spectral analysis for target detection: Assessment of polarimetry, *IEEE Transactions on Geoscience and Remote Sensing*, 41(12): 2725-2734.

Van Zyl, J. J., 2001. The Shuttle Radar Topography Mission (SRTM): a breakthrough in remote sensing of topography, *Acta Astronautica*, 48(5-12): 559-565.

Werner, M., 2001. Shuttle radar topography mission (SRTM) mission overview, *Frequenz*, 55(3-4): 75-79.

Wang, X., and C. Chen, 2016. Adaptive ship detection in SAR images using variance WIE-based method, *Signal, Image and Video Processing*, 10(7): 1219-1224.

Wang, C., M. Liao, and X. Li, 2008. Ship detection in SAR image based on the alpha-stable distribution. *Sensors*, 8(8): 4948-4960.