PERFORMANCE ANALYSIS OF SHIP DETECTION ALGORITHMS BASED ON KOMPSAT-5 SLC IMAGE AND AIS DATA

Donghan Kim (1), Yoon-Kyung Lee (1), Sang-Wan Kim (1)

[1] Sejong University, 209, Neungdong-ro, Gwangjin-gu, Seoul, Republic of Korea
Email: kimdonghan@sju.ac.kr; ykeunice.lee@gmail.com; swkim@sejong.edu

KEY WORDS: KOMPSAT-5, Ship detection, AIS

ABSTRACT: To protect maritime resources and national territory, continuous monitoring and prompt respond is essential. Synthetic Aperture Radar (SAR) images with wide coverage are effective for maritime monitoring, with little impact on weather and day-night conditions. However, due to the capacity of the SAR images and the speckle noise, it is difficult to reduce processing speed and detect the exact position of the ships. In this paper, we apply the variety ship detection algorithms fused with Human Visual Attention System (HVAS), Constant False Alarm Rate (CFAR) and Split-Beam (SB) to KOMPSAT-5 SLC image. KOMPSAT-5 is the first high resolution X-band SAR satellite developed by Korea Aerospace Research Institute (KARI). For the analysis, the KOMPSAT-5 image was compared with Automatic Identification System (AIS). The performance analysis of the ship detection algorithm by various combinations showed that the detection rate itself was high at the combination of HVAS-SB, but considering the error detection rate and processing speed, HVAS-SB-CFAR showed stable performance. Some ships detected in KOMPSAT-5 but not in AIS are due to the data absence and signal delay error from AIS. Meanwhile, SAR image also has some false alarms due to ship wakes and DEM error during masking land.

INTRODUCTION

Due to the depletion of limited land resources, interest and importance for marine sources is increasing, and thus, the number of ships engaged in illegal fishing activities is increasing. The management of illegal ships on the national maritime territory is an important issue not only for resources but also for military matters. Developed countries such as the United States, Canada, and Japan have established a ship surveillance system using SAR images that are favorable for weather and day and night conditions. Currently, South Korea does not establish a ship monitoring system using SAR images, so it needs to be developed. KOMPSAT-5 is Korea's first SAR satellite developed by KARI and is equipped with an x-band sensor which has a favorable resolution for monitoring ships. Ship monitoring can be applied through integration of KOMPSAT-5 with AIS which expressing ship location and information.

Ship detection, which is the most basic of ship surveillance, is divided into the method of detecting the ship itself and detecting the ship wakes generated when the ship moves. The detection of ship wakes is more complicated than the detection of the ship itself and is subject to the conditions in which the ship must move. In addition, the method of detecting the ship itself is preferred because the backscatter values from the ship is much stronger than the ship wake. Ship detection algorithms have been developed a lot before. Detection rate and processing speed are important factors in ship detection algorithms, but fulfill both is a challenge (Kim et al., 2018). The Constant False Alarm Rate (CFAR) is an algorithm that identifies the presence or absence of a target pixel by windowing the image (Gao et al., 2008). CFAR is still the most widely used algorithm for ship detection and vary according to the distribution used in windows. Although CFAR is an algorithm with very high detection accuracy, it has a disadvantage of very low processing speed because windows move one pixel at a time. Split-Beam (SB) is a technology that separates SAR images that are synthesized for a certain period of time in the Azimuth direction to produce images with time difference (Brekke et al., 2012). Ship detection algorithm using SB was developed at 2001(Iehara et al., 2001). SB ship detection algorithm calculates cross corrections of two separate images to detect ships and has the advantages that effectively categorize clutter. However, it also has the disadvantage of having low data processing speed. Pulsed Cosine Transform (PCT) is an algorithm that effectively highlights objects that stand out from the surrounding area in the images (Yu et al., 2009). Human Visual Attention System (HVAS) algorithm which developed on 2013 using PCT algorithm and characteristic that ships have a higher backscatter values than clutter area in SAR images (Amoon et al., 2013). HVAS has the advantage of detect ships very fast through Fourier transformations and thresholding. However, it is difficult to determine the appropriate threshold for both detection accuracy and false detection rate.

In this paper, ship detection algorithms CFAR, Split-Beam and HVAS are applied in various combinations to KOMPSAT-5 SAR SLC images. Considering the advantages and disadvantages of existing algorithms, the combination of ship detection algorithms consisted of HVAS-SB, HVAS-CFAR, HVAS-CFAR-SB, HVAS-SB, HVAS-SB-CFAR, and HVAS-SB-CFAR. Performance analysis was performed by comparing each detection rate, error rate, and processing speed.

RESEARCH AREA AND USED DATA

The study area was the west coast of Taean-gun, Chungcheongnam-do, Korea Peninsula (Figure 1). The west coast of Taean-gun has several ports such as Sinjin Port and Gunsan Port. Various types of fisheries are formed depending on the season, so ships move frequently at the west coast of Taean-gun (Kim et al., 2018). In this study, three KOMPSAT-5 images acquired on October 3, 2018 were used for ship detection (Table 1). Also, Automatic Identification System (AIS) data about image acquisition time was acquired used for detection performance analysis.

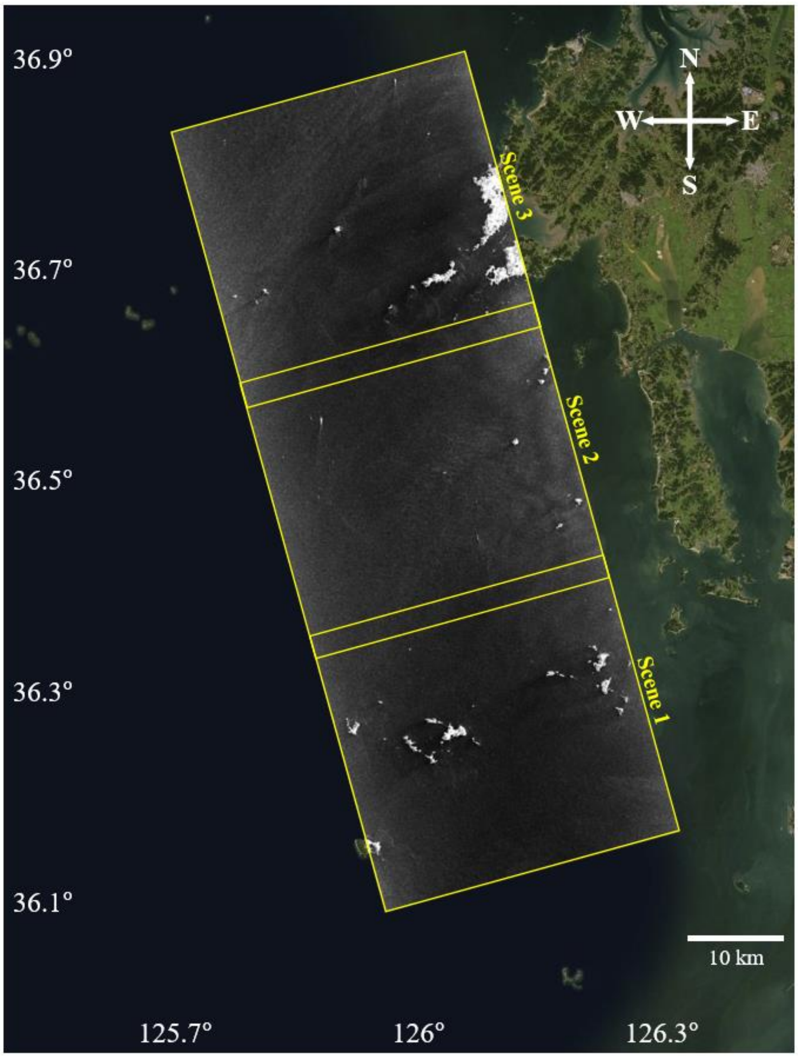

Figure 1. The research area.

Table 1. List of KOMPSAT-5 images

Scene number	Date (UTC)	Incidence Angle (degree)	Look direction	Mode	Resolution (m)
1	2018-10-03 20:45:49	35.4650	Left	Standard	2.02*3.67
2	2018-10-03 20:45:49	35.4575	Left	Standard	2.02*3.67
3	2018-10-03 20:45:49	35.4500	Left	Standard	2.02*3.67

METHODOLOGY

As mentioned in the introduction, this paper conducts ship detection performance analysis by fusing the characteristics of each algorithm. SAR Single Look Complex (SLC) data is used for the algorithm. SLC data is a SAR image with complex imagery and phase values. SLC image was used because SB is applied to SLC data format. Prior to ship detection, land masking is performed to improve the performance and detection rate of HVAS algorithm (Figure 2). At the land masking, since the masking was performed by converting the vector type SWBD into the SAR radar coordinate system, the processing speed is faster than the conventional method (Figure 3).

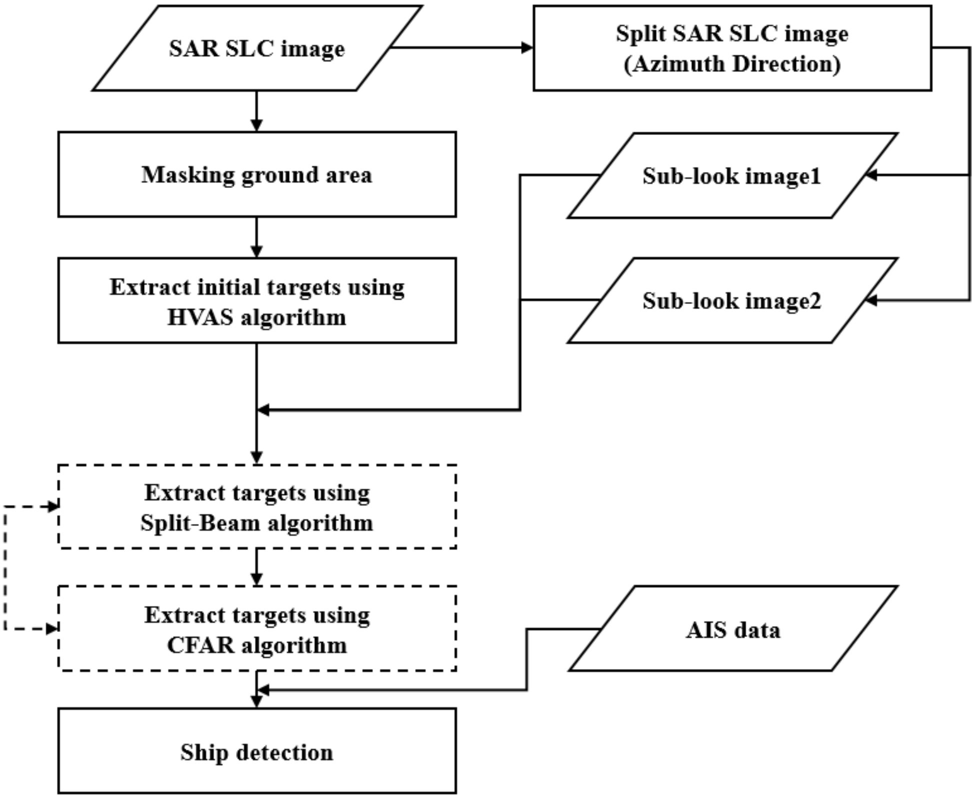

Figure 2. Flow chart of ship detection strategy.

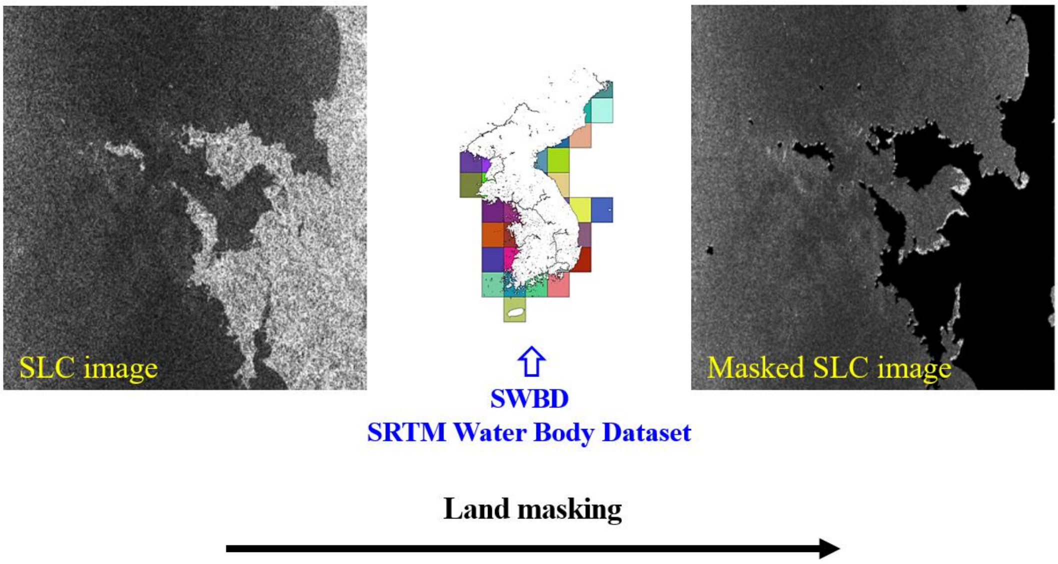

Figure 3. Process of the land masking.

HVAS algorithm

HVAS using DCT (Discrete Cosine Transform) is known to be faster and more accurate than CFAR. HVAS is one of the algorithms that apply the principle of the visual system to recognize the main objects in the image. This feature is used in combination with the characteristics of SAR images, that the ships are prominent compared to the low backscatter values of the ocean clutter (Amoon et al., 2013).

$$\begin{aligned} P &= sign[DCT(I)] \\ F &= DCT^{-1}(P) \\ I_{pct} &= G * F^2 \end{aligned} \tag{1}$$

Where sign is Signum Function, DCT is Discrete Cosine Transform and G is Gaussian Filter. Ship detection algorithms commonly performs HVAS algorithm first. This is because the processing speed of the HVAS algorithm is very fast and the detection rate increases as the threshold lowered. In this paper, we extract the initial target by strikingly lowering the threshold of the HVAS algorithm. Initial targets with high detection and false detection rates can be combined with other algorithms to reduce false detection rates.

SB algorithm

In the SB, two sub-look images with time difference are created by separating the SAR images in the azimuth direction. Next, cross correlation is performed with created sub-look patches with a size of 200*200 based in the input target positions. Falsely detected patches in the clutter region are not correlated because clutter is random over time period, and for patches with targets are correlated (Figure 4). This step filters out false detected patches with faster processing speed, because only the extracted targets are used for the processing.

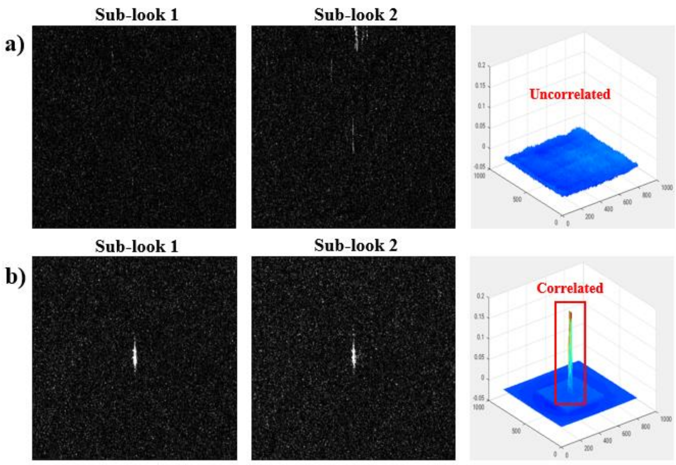

Figure 4. Correlation between false detected patch (a) and true detected patch (b).

CFAR algorithm

CFAR algorithm also generates a patch of 200*200 size based on the location of input targets to perform detection. In this paper, the distribution of CFAR window was used with a G0 model similar to the distribution of SAR images. CFAR is also performed only on extracted targets, so the processing speed is significantly faster than the full scene.

$$\begin{aligned} \hat{\alpha} &= -1 - \frac{nE(I^2)}{nE(I^2)-(n+1)E^2(I)} \\ \hat{\gamma} &= (-\hat{\alpha} - 1)E(I) \\ \mathbf{T} &= \hat{\gamma}(P_{fa}^{\frac{1}{\hat{\alpha}}} - 1) \end{aligned} \tag{2}$$

Where $\boldsymbol{I}$ is SAR image, $\boldsymbol{E}$ is average, $\boldsymbol{n}$ is number if looks, $\boldsymbol{P_{fa}}$ is given value of the false alarm probability and $\mathbf{T}$ is local threshold value.

EXPERIMENTAL RESULTS

Analysis of detection rate of ships were performed using AIS data as truth. A general Nearest Neighborhood (NN) method was used for matching SAR ship positions and AIS ship positions. According to various combinations of ship detection performance analysis, overall HVAS-SB processing speed and detection rate were high (Table 2). However, from the naked eye, there were a lot of false detected targets of the HVAS-SB performance result on the initial target of HVAS (Figure 5). Therefore, the use of only SB alone has a limitation because the false detection rate is higher than the detection rate. All three showed similar detection rate except HVAS-SB, and there was less false detection with the naked eye. CFAR has the disadvantage that the processing speed is very low as mentioned above. When performing CFAR on the initial target detected by HVAS, it can be seen that the processing speed is significantly lowered as the number of initial targets increases. In the case of HVAS-SB-CFAR, CFAR is performed after the target filtering through SB on the initial target of HVAS, so it can be confirmed that the target number to processing speed ratio is faster than other algorithms.

Table 2. Performance result of ship detection algorithms

Combinations	Scene number	Initial targets	Matching rate	Processing time
HVAS-SB	1	272	68.4 %	70 s
	2	609	75 %	85 s
	3	757	43.6 %	90 s
HVAS-CFAR	1	272	68.4 %	90 s
	2	609	66.6 %	210 s
	3	757	36 %	355 s
HVAS-CFAR-SB	1	272	63.1 %	130 s
	2	609	66.6 %	245 s
	3	757	36 %	385 s
HVAS-SB-CFAR	1	272	63.1 %	105 s
	2	609	66.6 %	205 s
	3	757	36.5 %	270 s

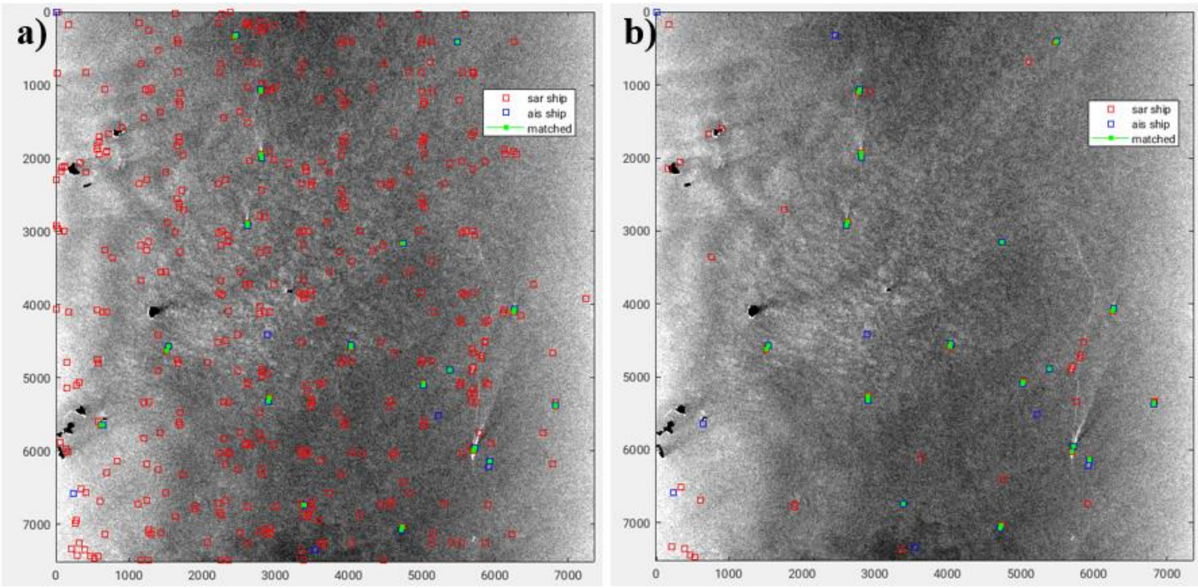

Figure 5. Result of ship detection. HVAS-SB (a) and HVAS-SB-CFAR (b).

CONCLUSIONS

In this paper, various ship detection algorithms are fused and performance analysis considering detection rate of the ships, false detection rate and processing speed is conducted. The performance analysis showed that HVAS-SB-CFAR is stable performance in consideration of detection rate, false detection rate and processing speed. In the performance analysis, the visual analysis was performed for the false detected rate analysis because it was judged that the reliability of the AIS truth was low because of its reception error and absent data. The detection rate was also low overall for reasons of AIS errors. In addition, false and misdetection occurred due to errors in land masking performed in preprocessing, limitation of SAR image resolution and ship wakes (Figure 6). It is believed that the misdetection and false detection generated from the ship detection will be improved through further analysis of the algorithms suitable for the KOMPSAT-5 data format and the step-by-step AIS-topping of the ships.

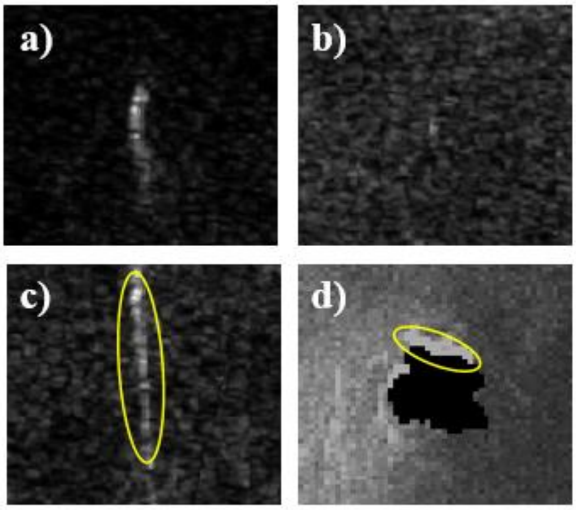

Figure 6. False detection occurred by AIS absent (a), ship wake (c), land masking (d) and misdetection occurred by SAR resolution (b).

ACKNOWLEDGEMENTS

This paper was supported by the Korea Institute of Marine Science & Technology (KIMST) in 2019 and funded by the Ministry of Oceans and Fisheries (MOF). (Base Research for Building Wide Integrated Surveillance System of Marine Territory).
Kompsat-5 satellite images were received from Korea Aerospace Research Institute (KARI) in this study.

REFERENCES

Amoon, M., Bozorgi, A., Rezai-rad, G. A. 2013. New method for ship detection in synthetic aperture radar imagery based on the human visual attention system. Journal of Applied Remote Sensing, 7 (1), 071599.

Brusch, S., Lehner, S., Fritz, T., Soccorsi, M., Soloviev, A., van Schie, B. 2011. Ship surveillance with TerraSAR-X. IEEE Transactions on Geoscience and Remote Sensing, 49 (3), pp. 1092-1103.

Brekke, C., Anfinsen, S. N., Larsen, Y. 2012. Subband extraction strategies in ship detection with the subaperture cross-correlation magnitude. IEEE Geoscience and Remote Sensing Letters, 10 (4), pp. 786-790.

Gao, G., Liu, L., Zhao, L., Shi, G., Kuang, G. 2008. An adaptive and fast CFAR algorithm based on automatic censoring for target detection in high-resolution SAR images. IEEE Transactions on Geoscience and Remote Sensing, 47 (6), pp. 1685-1697.

Iehara, M., Ouchi, K., Takami, I., Morimura, K., Kumano, S. 2001. Detection of ships using cross-correlation of split-look SAR images. IGARSS 2001. Scanning the Present and Resolving the Future. Proceedings. IEEE 2001 International Geoscience and Remote Sensing Symposium, 4, pp. 1807-1809.

Kim, S. W., Kim, D. H., Lee, Y. K. 2018. Operational ship monitoring based on integrated analysis of KOMPSAT-5 SAR and AIS data. Korean Journal of Remote Sensing, 34 (2), pp. 327-338.

Yu, Y., Wang, B., Zhang, L. 2009. Pulse discrete cosine transform for saliency-based visual attention. In Development and Learning, 2009. 2009 IEEE 8th International Conference on Development and Learning, pp. 1-6.