# Generation of Convergent Ship Traffic Dataset using Sentinel-1 Imagery and AIS

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**ABSTRACT**

Satellite-based ship detection has opened a new era of marine surveillance in recent decades. The ship detection using Sentinel-1, a Synthetic Aperture Radar (SAR) satellite image product, is an excellent measure of monitoring illegal activities at sea. Despite that, it is essential to compare the detection data to other convincible resources to verify whether the detected ships are indeed and to obtain further information. This paper introduces the procedure of matching the information of ships that are detected from Sentinel-1 imagery and Automatic Identification System (AIS) data. Since there are factors including the satellite's trajectory and scanning duration, appropriate data extraction from metadata of Sentinel-1 is required in advance. Azimuth shift, a symptom where a ship position moves to forward or backward of the SAR satellite proceeds in the imagery, also must be compensated. Consequently, a new dataset combining the information from Sentinel-1 and AIS is composed.

## 1. Introduction

Ship detection from Synthetic Aperture Radar (SAR) has opened a new era of maritime surveillance using space-borne remote sensing technology in recent decades. Sentinel-1 is a free available satellite image and is useful to monitor a wide sea area where the AIS signal is limited by its transmissible distance.

However, the detected ships from Sentinel-1 or other SAR images require to be verified with the following questions: "is it really a ship?" and "what a ship is it?" Surely, AIS for merchant ships of all nations and V-Pass for fishing vessels in South Korea make navigators and vessel traffic service officers (VTSO) identify ships around their own ship or harbor easily. Like radar displays on conventional ships shows the AIS information on the screen, and thus navigators and VTSO can identify the weird shape on the radar as a ship, the SAR image also requires matching information.

In fact, there are several procedures to match SAR and AIS; 1) estimation of satellite position, speed, and direction at the time(*T*) when the satellite detects the ship. 2) estimation of ship position, speed, and direction at *T*. 3) Compensation of azimuth shift which will be introduced in chapter 2. Therefore, this paper aims to briefly and simply introduce the theoretical background of matching SAR and AIS, and show the procedure of matching SAR detection and AIS.

## 2. Theoretical Background

Satellites can be categorized into geostationary and polar-orbit depending on their navigation style. The geostationary satellite navigates, keeping its monitoring target area in its sight (called 'field of view (FOV)' in remote-sensing terminology) while the latter navigate south pole to north pole recursively, and thus the satellite is able to monitor the global area. The Sentinel-1 image is from the type of polar-orbit satellite.

Sentinel-1 satellite proceeds to the north pole and south pole with a slight deviation and the direction is called azimuth direction (Fig. 1). On the other hand, SAR antenna transmits its microwave signal to its right-hand direction and is called slant range direction (the black bold line between satellite and ship 0,0 in Fig. 1). SAR image is being formed by scanning the slant range direction area while proceeding along to the azimuth direction (Fig. 1 & 2).

In general, SAR image is formed with the assumption of zero-Doppler condition except for the special purpose case, such as the Moving Target Indicator (MTI) to detect and supervise moving targets (Ouchi, 2009). Unlike MTI, Sentinel-1 has multiple purposes, and is vulnerable to detecting moving targets. Zero-Doppler is the condition where the Doppler effect is zero when there is no closer or farther movement between the satellite and the target ship. The satellite's zero-Doppler time (or azimuth time) is determined as its position when the sensor transmits its microwave signal to the target in slant range direction ($R_0$ in Fig.1). But if the ship moves closer to/farther away from the satellite (Fig. 1), it makes the Doppler effect and breaks the zero-Doppler assumption (Ouchi, 2009). Doppler effect brings a modification of Doppler frequency, and it subsequently causes a shift of the detected ship from its original position to the azimuth direction or its opposite direction; If the ship moves closer to the satellite it shifts toward the azimuth direction otherwise, vice versa (Ouchi, 2009; Song et al., 2020).

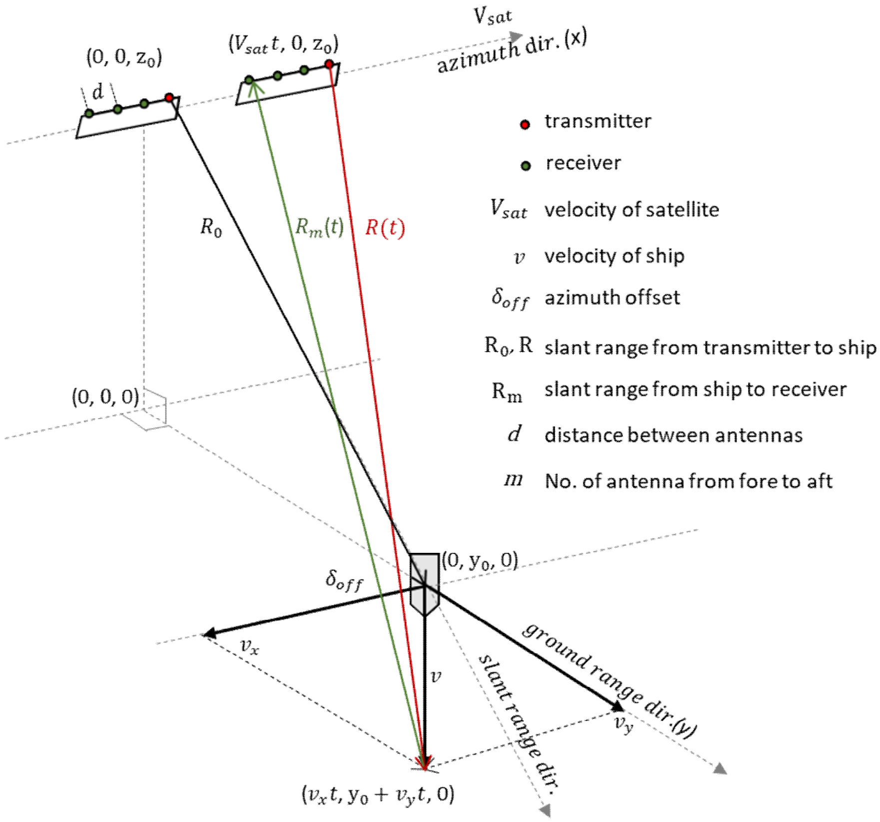


Figure.1 Geometry of SAR and azimuth shift. Recomposed image from Song et al. (2020).

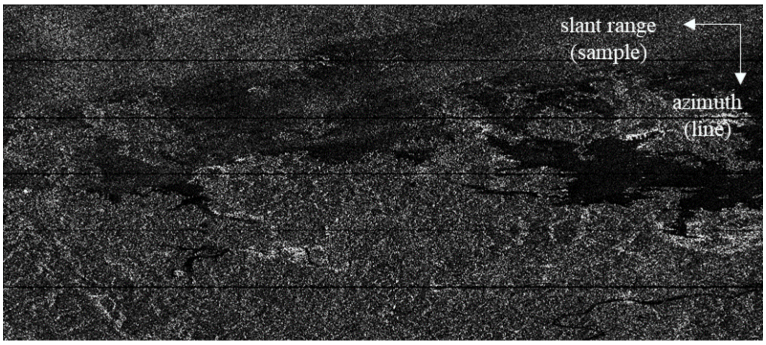


Figure 2. SAR image with azimuth direction and slant range direction.

## 3. Methodology

### 3.1 Estimation of satellite & ship position at azimuth Time

Prior to estimating the satellite position at azimuth time, it is significant to clean AIS data. AIS data has a large number of cases that contain abnormal trajectories that cannot be explained by their ship speed. Thus, the recursive thresholding-based outlier detection method has been devised in this study (Fig. 3). Then, the speed over ground (SOG) and course over ground (COG) are examined to whether they have a meaningful correlation to the outlier-removed AIS data.

Then, AIS trajectory is interpolated by using the Kinetic Interpolation (KI) method, suggested by Guo et al. (2021). KI interpolates the position and speed at the target time after calculating acceleration. Thus, it could simulate an overshooting trajectory of a ship (Fig. 4). Likewise, satellite trajectory also can be interpolated through KI (Fig. 5).

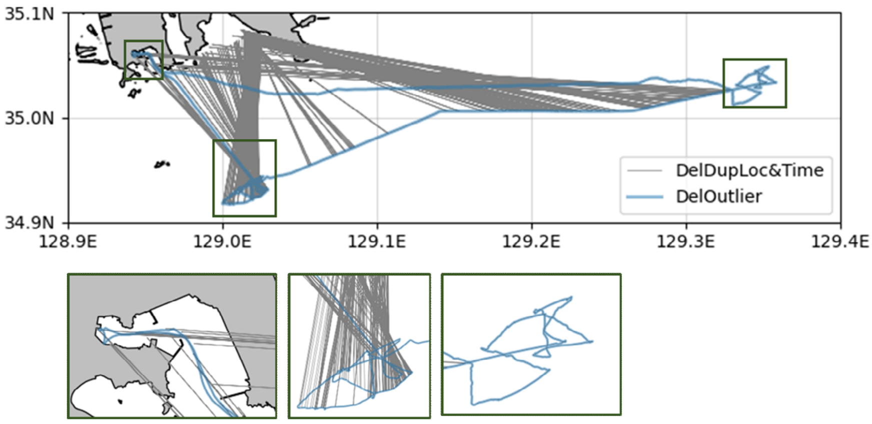


Figure 3. Recursive thresholding method results in AIS. Gray line indicates an abnormal trajectory after removing duplicated location and time while blue line indicates the outlier-removed trajectory.

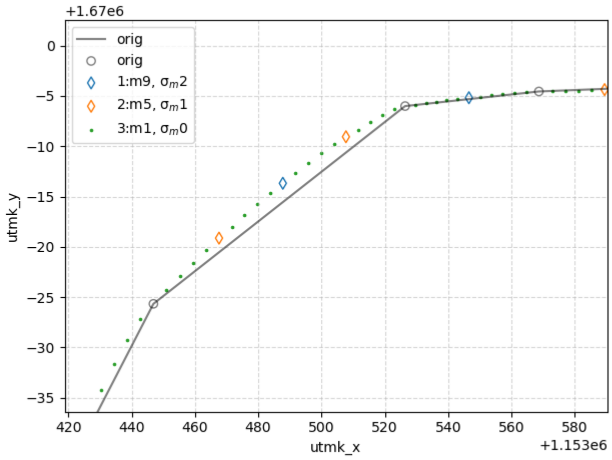


Figure 4. Kinetic Interpolation (KI) results in ship trajectory.

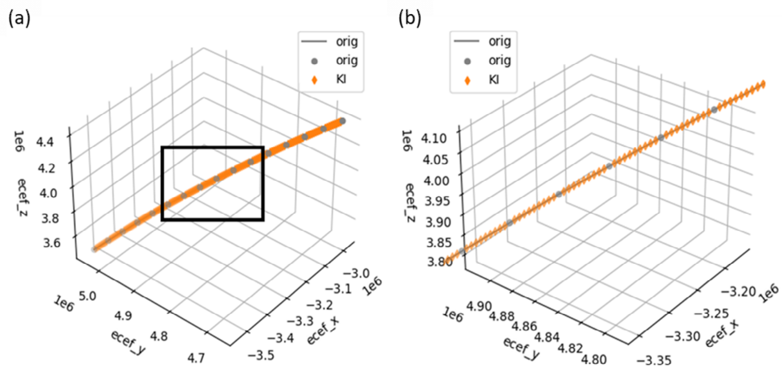


Figure 5. Kinetic Interpolation results in satellite orbit. (a) overall satellite orbit. Gray dot is the given position x, y, z of the satellite while orange dot represents the interpolated positions through KI. (b) zoom-in image of black square in a.

### 3.2 Convergent of Sentinel-1 and AIS

Since moving ships cause azimuth shift as aforementioned above, the shift should be compensated to match the AIS information to the detected ships by using Eq. (1), suggested by Song et al.(2021).

$$\delta_{off}=R_0/V_{sat}\cdot v_r \qquad \text{Eq. (1)}$$

$\delta_{off}$: distance of shift [m]
$R_0$: slant range between satellite and ship at azimuth time [m]
$V_{sat}$ : velocity of satellite along to azimuth direction [m/s]
$v_r$ : range direction component of SOG [m/s]

$$v_r = SOG\cdot cos(\theta_{sat}-COG+\pi/2) \qquad \text{Eq. (2)}$$

$SOG$ : speed over ground [m/s]
$\theta_{sat}$ : direction of satellite proceed in gyro bearing [rad]
$COG$ : direction of ship proceed in gyro bearing [rad]

Through Eq. 1 & 2, the shift distance and direction (azimuth direction or its opposite) is computed, and the distance compensates for the position of the AIS ship.

Ship detection is made on Jan. 27, 2018, 21:23:43-21:24:17 UTC on Busan adjacent sea. Then, AIS and V-Pass data are visualized with SAR detection (Fig. 6). SAR, AIS and V-Pass are marked with red, green, and yellow circles, respectively. As shown, SAR detection reaches more than AIS and V-Pass coverage (Fig. 6a). Ships on anchoring are almost matched by SAR and AIS while V-Pass ships are rarely matched (Fig. 6b, c). It can be seen because fishing vessels have smaller sizes than Sentinel-1's spatial resolution, and their unstable movement and longer reporting interval than that of AIS cause incorrect interpolation.

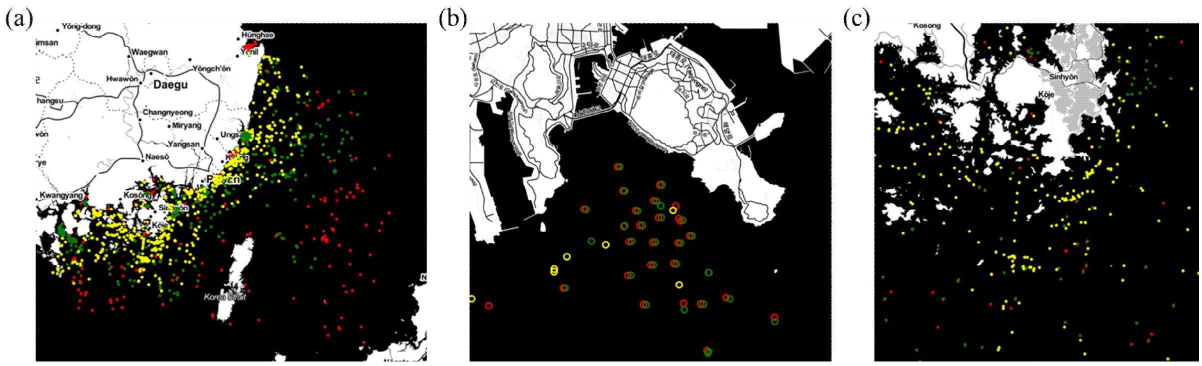


Figure 6. SAR, AIS, V-Pass location (a) Korea strait. (b) South of Yeongdo island in Busan. (c) South of Geoje. The circle of red, green, and yellow indicate SAR, AIS, V-Pass, respectively. The time is 2018.01.27 21:23:43-21:24:17.

The distances between SAR detection and marine traffic data were measured (Fig. 7). Since azimuth shift over 2km is impossible for conventional ships (< 40kn), the distance samples resampled for less than 2km. AIS has relatively short distances with a median 87m. On the other hand, V-Pass has a wider distribution than that of AIS with a median 246m.

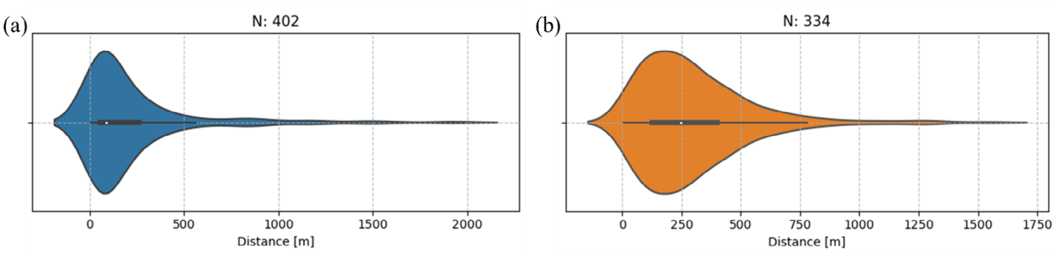


Figure 7. Matching distance from SAR. (a) SAR to AIS (b) SAR to V-Pass. The time is the same as Fig. 5

Individual ship images are generated after detection and matching (Fig. 8). Although small ships less than 20m in length are rarely detected by Sentinel-1 imagery, the other can be detected and generated through several image processing procedures. The complicated structure of the chemical tanker leads to the high intensity (Fig. 8a). The flat upper deck and complicated accommodation of the crude oil tanker cause both low and high intensity (Fig. 8b). Bulk carrier has similar intensity distribution to the crude oil tanker (Fig. 8c).

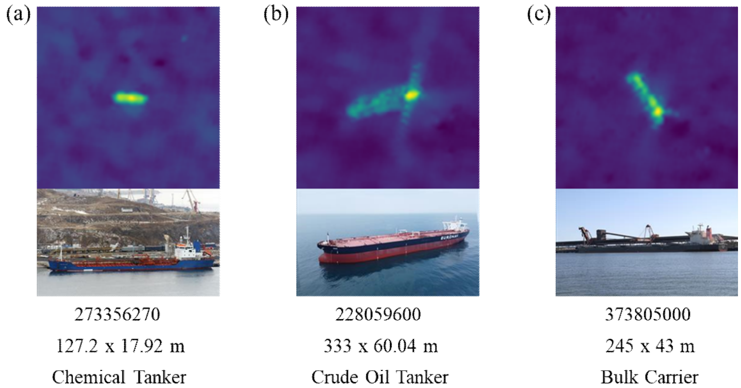


Figure 8. Individual ship images. (a) chemical tanker. (b) crude oil tanker. (c) bulk carrier.

**4. Results and Conclusion**

From the previous research and studies (Ouchi, 2009; Song et al., 2020; Guo et al., 2021), the methodology of matching AIS ship information to SAR detection has been settled and is being enhanced. A data cleaning method is newly devised in this study, and the KI method was applied to both AIS trajectory and satellite orbit. SAR detection results were matched with AIS and V-Pass. Due to V-Pass's long interval and fishing vessels size and their irregular movement leads to mismatching.

The further developed result will be introduced and discussed in ANC with a sample of the convergent dataset which is not shown in this paper.

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**Author's Biography**

Ho-Kun Jeon currently works at the Marine Bigdata Center, Korea Institute of Ocean Science and Technology (KIOST). He is on a Ph.D. at the University of Science and Technology (UST), majoring in Ocean and Coastal Engineering. He has a unique career as a navigation officer in merchant ships. The background enables him to study further maritime matters related to vessel operation. His current research field is marine safety and environment spatial and temporal analysis with remote sensing data.