Evaluating the velocity of ships from low-resolution SAR images

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Synthetic aperture radar (SAR) is a fundamental tool in maritime surveillance for its weather and daylight insensitivity and large swath. Position, size and bearing of a target ship can be extracted with high accuracy from a SAR image. Additionally, those images contain several cues to estimate the target velocity. However, dealing with spatial resolutions of tens of meters, the applicability of some approaches is questionable. We formerly experimented two velocity estimation methods based on the features extracted from the wake of a sailing ship [1]: one is based on the wavelength of the cusp waves characterizing the Kelvin wake pattern; the other is based on the typical azimuth shift that affects moving targets imaged by a SAR system. Both methods directly return the radial component of the ship speed; the azimuthal speed, and thus the complete velocity vector, can finally be reconstructed using the estimated ship track. The mentioned techniques rely on the detection of significant parts of the wake in the SAR image. This is not always possible, especially with low-resolution images, due to a combination of unfavorable incidence angles and rough status of the sea.

Another possibility to estimate the velocity of a ship is based on the different Doppler spectra characterizing static and moving targets. The shift between the centroid C_m of the Doppler spectrum estimated within a crop enclosing a moving target alone and the one, C_s, estimated within an equally sized area only including stationary sea is linearly related to the radial speed v_{rad} of the target, through the wavelength λ of the probing radar [2]:

$$v_{rad} \sim \lambda (C_s - C_m). \tag{1}$$

The evaluation of the Doppler centroids must be based on the Fourier analysis of SAR products that are different from those used by the wake-based techniques. Indeed, those two methods are based on spatial features, so the most important image characteristics for accuracy are the signal-to-noise ratio and the fidelity of the distances estimated from the images and the ones measured on the ground. These properties are found in SAR multi-look images projected on the ground, such as the IW-GRDH (interferometric, wide-swath, ground-range detected, high-resolution) products from the Sentinel 1 C-band SAR we used for our experiments, with a spatial resolution of about 10 m. Conversely, the Doppler shift method needs complex images, not mediated over different looks, such as the SLC (single-look, complex) Sentinel 1 products. Our experiments showed that an additional requirement must be posed to reach accurate results. Indeed, we found that the IW acquisition mode is not suitable to our aim, since it is obtained through the composition of different sub-swaths, implying a resampling of the component SLC images. The Sentinel 1 products that need to be considered to carry out the Doppler centroid estimation are the stripmap (SM) ones. At the expense of a narrower swath (80 km against the 250 km of the IW mode), the SM products offer unaltered complex data in azimuth and slant range coordinates. Unfortunately, the Sentinel data hub does not offer many SM-SLC images (thousands, against hundreds of thousands IW-SLC, including the ones that do not contain ocean regions), so the validation of our results could not rely on an abundant data set. Anyway, we found some images where both the azimuth shift and the Doppler shift methods can be applied, and the velocities estimated were similar in the two cases, with a correlation coefficient of 85%, which becomes 97% if a few outliers are removed from the data. An actual validation will be possible when SM-SLC images equipped with ground truth velocities are available. We plan to pursue this result in the future, by using paired AIS data.

1. M. Reggiannini, L. Bedini, “Synthetic aperture radar processing for vessel kinematics estimation”, *Proceedings (MDPI)*, Vol. 2, 2018. doi:10.3390/proceedings2020091.

2. M. Reggiannini, “Ship kinematics estimation based on Doppler centroid deviation in synthetic aperture radar images”, CNR-ISTI Working Paper 457047, 2021.

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