A Fast Ship Size and Heading Angle Estimation Method for Focused SAR and ISAR Images

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***Abstract*—Ship size estimation is important for ship classification and recognition applications. In this paper a novel and fast ship size and heading angle estimation method for focused synthetic aperture radar (SAR) and ISAR (inverse SAR) images is proposed. The eigenvalue information of the detected ship pixel positions are used for estimating the size and heading angle of the ship. The proposed method is compared with several state-of-the-art algorithms. Real Sentinel-1 spaceborne radar datasets are used for evaluation.**

***Index Terms*—synthetic aperture radar (SAR), spaceborne, ships, maritime safety**

I. Introduction

Ship detection is crucial for monitoring several maritime threats such as illegal fishing, migrant boats and piracy. Apart from detection, ship size and heading angle estimation are necessary for ship classification and for obtaining its moving direction, respectively. For doing this, air- and spaceborne radar sensors can be considered as a suitable choice due to their all-weather and day-night acquisition capabilities. Airborne radars allow for shorter revisits and longer observation times at the cost of limited spatial coverage while the spaceborne radars provide large coverage, and, hence, wide area monitoring with the disadvantage of longer revisit times [1].

In the open literature there exist several ship size and heading angle estimation methods. One of the most prominent ones is based on the Radon transform [2], [3]. It takes a 2D image containing the object of interest as an input and computes the length, width and orientation of the object. Another widely used state-of-the-art method is based on the elliptical fitting to the detected edge pixels of the ship [4], [5]. However, noisy and sparse border pixels may result in the overestimation of the ship dimensions as shown, for example, by the red ellipse in Fig. 2. Furthermore, there are also some computationally intensive deep-learning-based approaches [6].

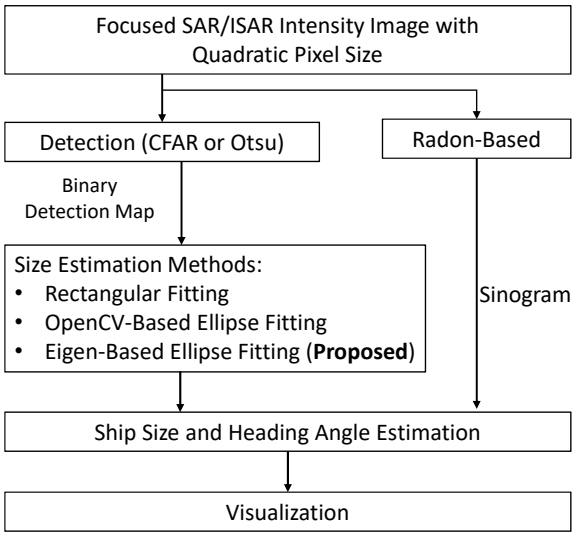

Fig. 1: Processing framework for ship size estimation using focused SAR and ISAR images as inputs.

In this paper we propose a fast and accurate ship size and heading angle estimation method. It utilizes the eigenpair of the detected pixel positions of the ship and fit an ellipse for determining its length, width (= beam) and heading angle. The proposed method is compared with the state-of-the-art algorithms. Focused images of actual ships present in Sentinel-1 SAR datasets are used for evaluation purposes.

The proposed method is applicable not only to focused air- or spaceborne SAR images but also to inverse SAR (ISAR) images [7]. Furthermore, the

proposed method is also intended to be integrated into the overall MMTI (maritime moving target indication) processing framework for the future compact HAP-SAR (high-altitude platform SAR) radar sensor [8] which is currently being developed at the Microwaves and Radar Institute of DLR (German Aerospace Center) and which shall be integrated into the DLR HAP [9].

II. Estimation Methodology

Fig. 1 shows the processing flowchart for the size and heading angle estimation. Focused SAR/ISAR images mapped to ground with equal pixel size in ground range and azimuth direction are needed as input. For the *Rectangular Fitting*, *OpenCV-Based* ellipse fitting and the proposed *Eigen-Based* ellipse fitting methods, a binary detection map is first obtained after applying, for instance, a constant false alarm rate (CFAR) or Otsu-based detection technique on the focused images [10], [11]. Then the aforementioned methods are applied on the detected pixel positions of the ship. On the other hand, the *Radon-Based* method is applied directly onto the image. Afterwards size and heading angle are estimated followed by the visualization.

III. State-of-the-Art Methods

A. Rectangular Fitting

In this method a rectangle is fit to the detected ship pixel positions. The maximum and the minimum pixel positions both in the azimuth and in the range directions are used for estimating the length and width of the ship, respectively. Note that this method does not compute the heading angle of the ship and for the ship length in general an underestimation and for the beam an overestimation is expected. However, this method can be used for the automatic ship data patch extraction from the image [4].

B. OpenCV-Based Elliptical Fitting

For this method function called **cv2.fitEillipse** in the OpenCV library [12] of Python [13] is used. To use this method first the border points of the ship are extracted using **scipy.spatial.ConvexHull** function. These edge-points are then given as an input to the **cv2.fitEillipse** function. The function returns the center, major and minor axes of the ellipse and its orientation as the output. The major and minor axes of the ellipse are the target extents [12].

C. Radon-Based

This method uses the Radon transform [2]. It performs line integral to the intensity of a 2D image along different angles, known as projection angles. The angle that gives the highest intensity in the sinogram corresponds to the heading angle. With the known heading angle, the width and the length of the object can be estimated [3]. The Radon transform is implemented using the **skimage.transform.radon** Python function.

IV. Proposed Eigen-Based Elliptical Fitting

For the proposed method first a covariance matrix is computed using the detected ship pixels positions. Then the eigenvalues and eigenvectors of the estimated covariance matrix are estimated after performing the eigenvalue decomposition (EVD).

The EVD of the covariance matrix $\hat{\mathbf{C}}_{\mathrm{ship}}$ can be expressed as [14]

$$\hat{\mathbf{C}}_{\mathrm{ship}} = \mathbf{V}\lambda\mathbf{V}^{-1}, \tag{1}$$

The terms $\mathbf{V}$ and λ are the eigenvectors and eigenvalues, respectively. The largest and smallest eigenvalues correspond to the semi-major and semi-minor axes of the ellipse, respectively, and the eigenvector corresponding to the largest eigenvalue gives the orientation of the ellipse.

After estimating the eigenvalues and the eigenvectors, the length, the beam, and the orientation of the fitted ellipse w.r.t the horizontal image axis can be computed, as

$$\hat{l}_{\mathrm{ship}} = 2\sqrt{k\lambda_1}, \tag{2}$$

$$\hat{b}_{\mathrm{ship}} = 2\sqrt{k\lambda_2}, \tag{3}$$

$$\hat{\theta}_{\mathrm{ship}} = \arctan 2\left(\frac{V_{1,\mathrm{v}}}{V_{1,\mathrm{h}}}\right), \tag{4}$$

where $\theta \in [-\pi, \pi]$, k is the scale factor and $\mathbf{V}_1$ is the eigenvector that corresponds to the largest eigenvalue λ_1. The terms $V_{1,\mathrm{v}}$ and $V_{1,\mathrm{h}}$ are the vertical and the horizontal components of $\mathbf{V}_1$, respectively.

The scale factor k = 3.21 corresponding to the 80% confidence interval is used which is found suitable for the data which have been studied here and led to the most accurate results.

V. Experimental Results

In this section size estimation results using the proposed method are presented and the results are compared with the state-of-the-art methods. Fully focused images acquired with the ESA Sentinel-1 SAR satellite are used for the evaluation. For our investigations we

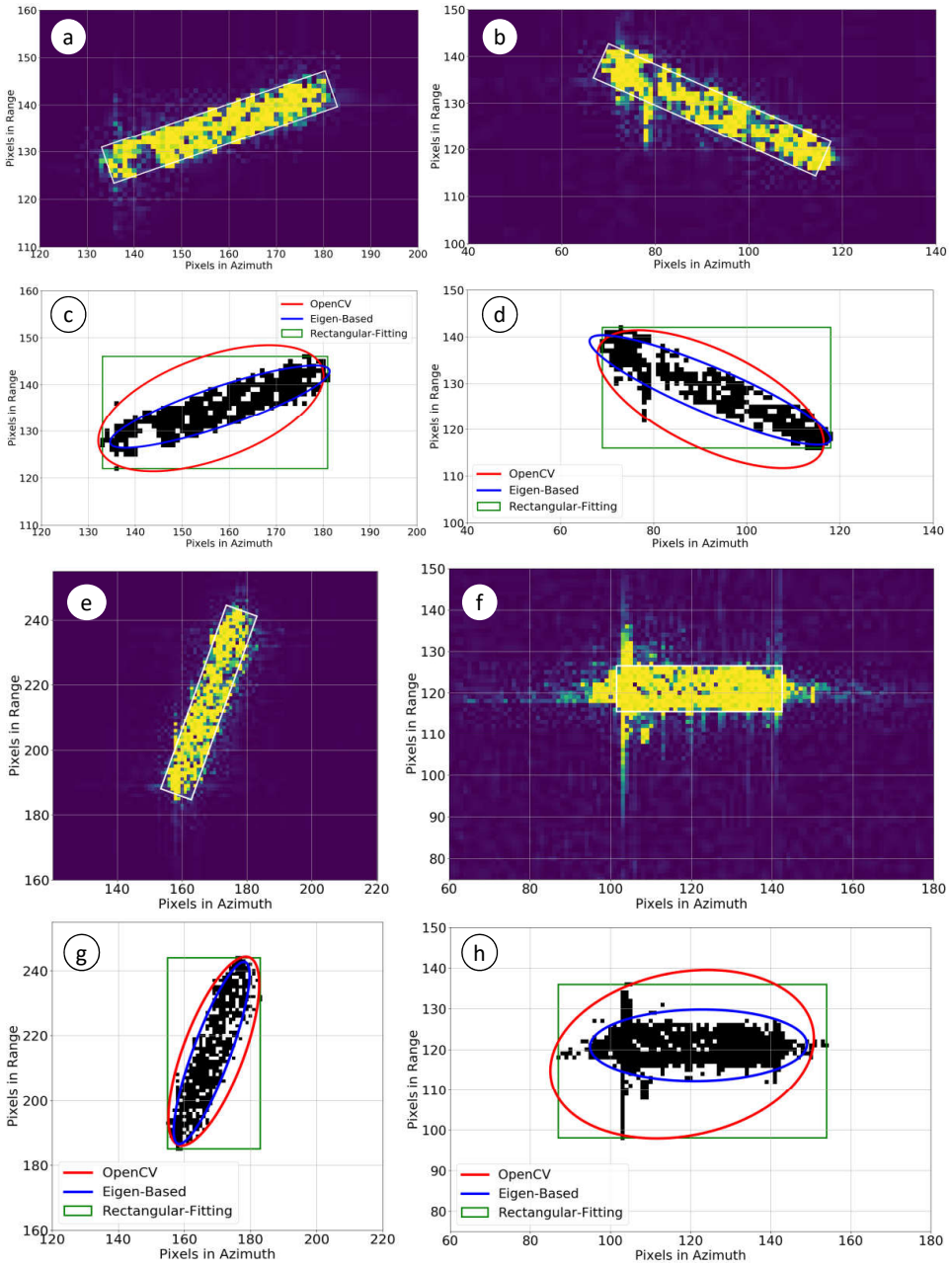

Fig. 2: Size and angle estimation results. Figures (a), (b), (e) and (f) are focused ships in Sentinel-1 SAR data with different sizes and orientation angles. Figures (c), (d), (g) and (h) are their corresponding binary detection maps obtained after applying the Otsu's thresholding method [10]. The white rectangles in the images are the results obtained from the *Radon-Based* method. The blue ellipses in the binary detection maps are obtained with our proposed *Eigen-Based* method. All images in the figure originally have dimensions of 256 x 256 in pixels. They are truncated for the visualization purposes.

have selected four images from the freely available Sentinel-1 SAR dataset [15]. In these images the ships have different orientation angles. The results are shown in Fig. 2.

As shown in Fig. 2, the *Rectangular Fitting* method does not represent the actual ship size and provide no angle information at all, since it only creates a bounding box by taking the minimum and the max-

TABLE I: Ship length, beam and orientation angle estimation results using different methods. Ships (a), (b), (e) and (f) in the table are also shown in Fig. 2.

Ships	Methods	Length [pixels]	Beam [pixels]	Orientation [°]
a	Rectangular Fitting	48	24	0.0
	OpenCV-Based	50	21	20.1
	Radon-Based	50	8	18.9
	Eigen-Based	49	9	18.6
b	Rectangular Fitting	49	26	0.0
	OpenCV-Based	53	21	-25.52
	Radon-Based	52	8	-23.9
	Eigen-Based	55	9	-25.5
e	Rectangular Fitting	60	10	0.0
	OpenCV-Based	62	18	69.7
	Radon-Based	60	10	70.3
	Eigen-Based	60	11	70.1
f	Rectangular Fitting	67	38	0.0
	OpenCV-Based	66	40	11.1
	Radon-Based	41	11	0.0
	Eigen-Based	54	17	0.7

imum pixel positions of the detected ship. For all the images in the figure, the *OpenCV-Based* method overestimate the ship dimensions due to the sparse and noisy boundary pixels. On the other hand, the *Radon-Based* and the proposed *Eigen-Based* method fit very well with the ship shapes and their orientations.

No ground truth data are available for the used SAR images but visually both *Radon-Based* and the proposed method appeared to fit well with the ship dimensions. The results for the ships in Fig. 2 are also summarized in Table I.

As shown in Table I the estimated ship dimensions and the orientation angles obtained using both *Radon-Based* and the proposed *Eigen-Based* methods are nearly the same.

Furthermore, a processing time evaluation was also carried out for all the methods. Each method for each ship was executed hundred times and the corresponding average processing times were calculated. For a given image patch of 256 x 256 pixels, the proposed *Eigen-Based*, *OpenCV-Based*, *Rectangular Fitting* and *Radon-Based* approaches take approximately 70 μs, 20 μs, 0.13 ms and 0.5 s, respectively. The *Radon-Based* method is found $\approx$ 6000 times slower than the proposed *Eigen-Based* method. This is because the *Radon-Based* method needs the entire image patch for its calculations whereas the proposed method is applied only on the pixel-based detections (cf. Fig. 1).

Therefore, it can be inferred that both in terms of processing time and estimation accuracy, the proposed *Eigen-Based* method is clearly a big advantage, especially for the DLR HAP with limited onboard processing resources. Moreover, the real-time capability shown by the proposed method also makes it very attractive for scenarios involving wide area monitoring with numerous targets of opportunity.

VI. Conclusion

In this paper a novel eigenvalue decomposition-based ship size estimation method is proposed. Focused spaceborne SAR images containing ships with different sizes and orientations were used for the investigations. In comparison with the state-of-the-art methods, the proposed *Eigen-Based* approach was not only found accurate but also computationally very fast. For instance, compared to the state-of-the-art *Radon-Based* method the proposed method is nearly 6000 times faster, making it a suitable choice for future real-time ship monitoring and ship classification applications.

A more detailed and comprehensive investigation on several state-of-the-art methods and the proposed method can be found in [16].

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