A Method for Pose Estimation of Ship Target from SAR ROI Based on Ellipse Fitting

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Abstract— Pose estimation of target ROIs (region of interest) is an essential approach in Synthetic Aperture Radar (SAR) image interpretation. It brings high efficiency and fine accuracy in the process of target recognition and classification with accurate pose estimation. In this paper, firstly, the typical methods of target pose estimation are introduced, and the advantages and disadvantages of them are analyzed. Then, focusing on ship targets in SAR images, a novel method based on ellipse fitting is proposed to estimate the pose of the ship. According to the fact that the contour shape of ship target is generally similar to an ellipse in medium resolution SAR images, the principal axis of the fitted ellipse can be used to estimate the attitude angle of the ship. The ship target ROI is separated from the background and the contour of the target is extracted to fit an ellipse through a least squares ellipse fitting method. Although the contour of the ship target is generally coarse, the ellipse can be stably achieved by the complex real contour and a minority of singular points does not affect the final result significantly. At last, a number of experiments with ship target ROIs from TerraSAR-X SAR data are explored, and the mean error is less than 1.0°, which shows the robustness and validity of the proposed method in ship pose estimation with SAR images.

1. INTRODUCTION

Pose estimation of movable targets is very important for automatic target recognition (ATR) in SAR (Synthetic Aperture Radar) system. In template-based SAR ATR system, classification is applied by comparing the unknown targets SAR images with the SAR templates of known targets. Since the sensitivity of SAR images to the attitude angle of the targets, for each kind of the target, a series of SAR images in different attitude angles are contained in the templates. As a result, the template library is with massive data for supporting the classification, and it greatly increases the load of computation of template matching (classification). Therefore, the speed of template matching will be significantly accelerated and the efficiency of SAR ATR system will be much improved, if the attitude angle of unknown target is estimated in SAR image before classification and then the SAR image of unknown target is matched with the template of the known target with a certain attitude angle in the template library. While in model-based system for automatic target recognition, the library stores physical or theoretical models of samples, by processing which, images or feature vectors with any pose and under any arrangement can be estimated. The hypothesis of target's type, pose and so on is continually modified until it is matched well enough with the SAR image containing an unknown target or feature vectors extracted from the SAR image, through which the classification is explored. Similarly, if the pose of a target can be estimated by the SAR image accurately, feature vectors extracted from the model can be matched directly with that of the SAR image so that the efficiency of the SAR ATR system is improved.

Generally, pose estimation based on SAR image should meet two requirements. Firstly, it should be accurate, which is the most important and required by correct classification. Secondly it also should be robust against target deployment variation.

2. PREVIOUS METHODS

There are two classic methods for pose estimation of target, the leading edge method and the encapsulating box method [2]. The former usually focuses on the target of vehicle, whose contour includes a long straight line named the leading edge. In SAR images, however, it does not show the same effectiveness to the ship target, since the straightness and uniqueness of ship's long edge is not obvious enough. It is hard to choose the leading edge of the ship target properly and if the wrong choice is made, the estimation error will be great. The latter method ascertains the attitude angle through rotating the encapsulating rectangle of target. It usually lacks precision. Besides, plenty of other algorithms have been published on this topic. For example, Kefeng Ji [1], et al. used the linear regression strategy to find the line around which the scattering centers distribute. It is easy and fast, but still not accurate enough. Sometimes it is arbitrary and reluctant to fit a line to a ship target in SAR images. The experimental results of the three methods above are analyzed in Section 4.

Most of pose estimation methods depend much on the quality of target extraction from SAR images. If the extraction is not good enough, this kind of method would become unstable. Unfortunately, noise and clutters of SAR images always bring great influence to the separation. In this paper, therefore, a new method for pose estimation, which is more robust and valid, is introduced.

3. A METHOD FOR POSE ESTIMATION OF SHIP TARGET BASED ON ELLIPSE FITTING

The principal axis of the fitted ellipse can be used to estimate the attitude angle of the ship. There is a priori knowledge that the contour shape of ship target is generally similar to an ellipse in medium resolution SAR images, so fitting an ellipse to a ship target is reasonable. The flow chart of the proposed method is shown in Fig. 1. The target is firstly separated from the background and the contour of the target is extracted for ellipse fitting. Then, an ellipse is fitted to the whole contour data. Finally the major axis of the ellipse indicates the direction of the ship target.

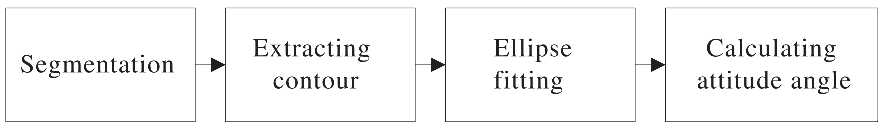
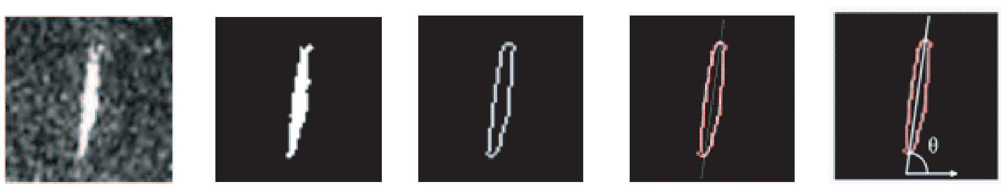


Figure 1: Flow chart of the proposed method.

3.1. Extraction of Contour Data

The 2-D OTSU segmentation algorithm is explored to deal with the ship target ROI (Fig. 2(a)). After the morphological image processing, the result is shown as Fig. 2(b), in which the connective region represents the ship target. Then the Canny operator is used to extract the contour of the connective region (Fig. 2(c)).



(a) (b) (c) (d) (e)

Figure 2: Schematic diagram of the proposed method. (a) Ship target clip. (b) Extracted target. (c) Extracted contour. (d) Fitted ellipse. (e) Attitude angle.

3.2. Ellipse Fitting

Ellipse fitting is the most important step in the method. The direct ellipse-specific fitting algorithm, proposed in Ref. [4], is used to fit an ellipse to the contour data. The precision of the ellipse fitting method is even stable and convinced enough for obit fitting of the satellite [5]. A general conic can be represented by an implicit second order polynomial:

$$F(\mathbf{a}, \mathbf{x}) = \mathbf{a} \cdot \mathbf{x} = ax^2 + bxy + cy^2 + dx + ey + f = 0 \tag{1}$$

where $\mathbf{a} = [a\ b\ c\ d\ e\ f]^T$ and $\mathbf{x} = [x^2\ xy\ y^2\ x\ y\ 1]^T$. $F(\mathbf{a}; \mathbf{x}_i)$ is called the "algebraic distance" of a point (x, y) to the conic $F(\mathbf{a}; \mathbf{x}) = 0$. The fitted conic can be ascertained by minimizing the sum of squared algebraic distances of the curve to the N data points $\mathbf{x}_i$.

$$D(\mathbf{a}) = \sum_{i=1}^{N} F(\mathbf{x}_i)^2 \tag{2}$$

In order to force the the conic to be an ellipse and make the solution simple, Andrew imposes the quadratic constraint $4ac - b^2 = 1$, which may be expressed in the matrix form $\mathbf{a}^T\mathbf{C}\mathbf{a} = 1$ as

$$\mathbf{a}^T \begin{pmatrix} 0 & 0 & 2 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \mathbf{a} = 1$$

where $\mathbf{C}$ expresses the constraint. Since Bookstein [3] showed if a quadratic constraint is set on the parameters the minimization (2) can be solved by considering the eigenvalue system:

$$\mathbf{D}^T\mathbf{D}\mathbf{a} = \lambda\mathbf{C}\mathbf{a}$$

where $\mathbf{D} = [\mathbf{x}_1\ \mathbf{x}_2\ \dots\ \mathbf{x}_n]^T$, the constrained ellipse fitting problem may be rewritten as the system

$$\mathbf{D}^T\mathbf{D}\mathbf{a} = \lambda\mathbf{C}\mathbf{a} \tag{3}$$

$$\mathbf{a}^T\mathbf{C}\mathbf{a} = 1 \tag{4}$$

The Ref. [4] stated the one-to-one relationship between the eigenvalues and eigenvectors, the solutions of (3) subject to the constraint (4). Finally, it proved that (3) has exactly one positive eigenvalue $\lambda_i > 0$, giving the unique solution $\mathbf{a}_i$ to (4). Therefore the problem can be solved and the ellipse can be ascertained by $\mathbf{a}_i$. Fig. 2(d) shows the fitted ellipse of the contour of Fig. 2(c).

3.3. Calculation of the Attitude Angle

The major axis is got from the fitted ellipse calculated in Subsection 3.2. The angle that the line of the major axis rotates counterclockwise to the positive direction of range is defined to be the attitude angle of the ship target, as θ in Fig. 2(e).

It should be noted that almost all of the existing methods for pose estimation based on SAR images cannot solve the problem of 180° uncertainty. Actually this problem does not cause large amount of computation. Therefore it is not discussed in this paper.

4. EXPERIMENTAL RESULTS

In order to verify the algorithm performance, 20 ship target clips extracted from the TerraSAR-X SAR images are used for experiments. This section presents some typical ones which illustrate the validness and robustness of the new method. The ROI clips, extracted contours and fitted ellipse are shown in Fig. 3. The experimental results, including the previous methods reviewed in Section 2 and the proposed method, are shown in Table 1. The performance of the proposed method is obviously better than the other and its mean error is 0.9°.

Sometimes the contours may not be ideal enough, e.g., Figs. 3(d), (e) and (f), in which some singular points, caused by noise and side lobe, make the shapes irregular. Under these circumstances, however, the proposed method, compared with other methods in Table 1, still maintain its accuracy. These experiments show that it is appropriate to introduce the priori acknowledge of the high similarity between a ship contour and an ellipse. The influence, made by singular points,

Table 1: Experimental data.

	Real attitude angle	Leading edge method	Encapsulating box method	Linear regression method	The proposed method
Clip. 0	82.8°	88.1°	82°	82.7°	82.1°
Clip. 1	83.1°	86.5°	83°	83.3°	83.4°
Clip. 2	138.2°	125.6°	146°	135.2°	138.0°
Clip. 3	176.5°	179.6°	168°	158.2°	174.2°
Clip. 4	153.9°	140.3°	160°	146.9°	154.9°
Clip. 5	32.1°	38.7°	34°	38.7°	31.9°

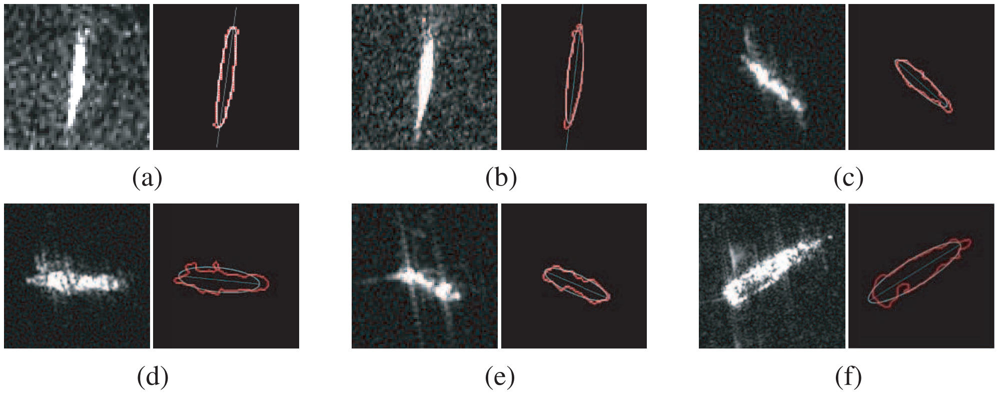


Figure 3: Pictures of some experiments. (a) Clip. 1. (b) Clip. 2. (c) Clip. 3. (d) Clip. 4. (e) Clip. 5. (f) Clip. 6.

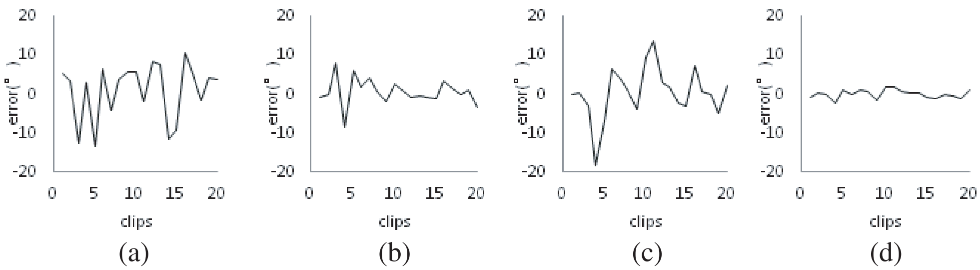


Figure 4: Error distribution of the four methods. (a) Leading edge method. (b) Encapsulating box method. (c) Linear regression method. (d) The proposed method.

to the result of the ellipse fitting algorithm is limited, since most points of the contour are in accord with the real shape of the ship target, which reflects the robustness of the method. All of the experimental results are presented in Fig. 4 in the form of diagram, which show the excellent performance of the proposed algorithm.

5. CONCLUSION

Nowadays SAR image interpretation is widely used in marine management and ocean survey and the pose estimation of ships plays an important role in this process. This paper focuses on the shape of ship target and presents a new method for pose estimation, ftting an ellipse to the ship contour through the least square fitting algorithm. Experiments with twenty SAR ship ROIs have proved its validity and robustness. Besides, it is no doubt that the method is timesaving, since the main computation is used in only once least square fitting.

There is still room for improvement in this method. It can be expected that if the contour data are filtered to eliminate the singular points, the fitted ellipse will be more similiar to the ship target and the pose estimation will be more accurate. What's more, when the fitting similarity is high enough, we can even use the fitted ellipses, instead of the images, to extract geometric information and other features of the ship target, avoiding all kinds of interferences in SAR images. These will be studied in our further research in the future.

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