Discrimination of Ship’s Bow in SAR Image

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Abstract. Discrimination of ship’s bow is a great application for marine surveillance in synthetic aperture radar (SAR) image. The real ship contour is approximately elliptical and the bow’s curvature is significantly larger than the stern’s curvature. The increasing resolution of SAR image makes ship target appear to be more structured and shaped which makes discrimination of ship’s bow possibly in SAR image. In this paper, we advance a method for discrimination of ship’s bow which includes two important parts. The first part, we use the gradient vector flow (GVF) snake model with elliptical constraint (EC) to get a more realistic ship contour for curve fitting. The second part, we use the least squares quadratic polynomial curve fitting to fit the two ends of the contour along the ship’s main shaft. The bigger absolute value of second order polynomial fitting coefficients, the more curved the rigid curve. The more curved end is identified as the ship’s bow. Experiments performed on detected small-size ship slices which also called regions of interest (ROI). These ROI slices which come from RADARSAT-2 data and one ROI slice contains only one ship target. Experiment results illustrate the effective performance of proposed method on discrimination for the ship’s bow in SAR image.

1. Introduction
SAR, independent with weather and illumination conditions, is widely used in maritime surveillance. Ship target supervisor using SAR data plays an important role in the field of maritime surveillance [1]. In order to get the ship’s moving trend, we need to discriminate which end is the ship’s bow. Earlier works in the literature focus on ship’s bow using wake signatures. However, it is found that ship backscatter is robust and independent of the sea state whereas wakes are often not visible at large incident angles and long wavelengths [2]. Because of these reasons along with the fact that stationary and slow moving ships do not create wakes, the focus of the later literature move on to the feature of the ship target itself. The increasing resolution of SAR images make the ship targets appear to be more structured and shaped.

The real ship target’s contour is regular. So, we can use the least squares quadratic polynomial curve fitting to fit two ends of the contour along the ship’s main shaft, compare two the second order polynomial fitting coefficients of the ends to get the bow.

Before fitting step, we need to get a good contour of the ship’s edge. In high resolution SAR image, the ship target general close fitting for the elliptical area of high brightness, “ghosting” and “sidelobe” will only in the local change of ship target geometry, and less influence on the whole contour. So, we can use the GVF snake model with EC to extract the ship target precisely and the get its contour [3].

Section 2 of this paper demonstrates the GVF snake model with EC which can get the precise ship’s contour. Section 3 details using the least squares quadratic polynomial curve fitting to fit the
two ends of the contour along the ship’s main shaft and the whole process of discrimination of ship’s bow. Section 4, Experimental Results. Section 5, Conclusion.

2. GVF snake with EC

2.1. Snake model and GVF
Snake model is the classic parameter active contour model. Snake model gets the initial contour of a closed curve near the target’s border, internal force and external force generated when we minimize the energy. The contour curve has some deformations under the joint action of its internal forces and image data’s external forces. The final result of deformation is to make the contour curve be the most similar to the real target’s contour. Snake contour usually be represented by a curve $M(s) = (x(s), y(s)), s \in [0, 1]$. The snake contour deforms to minimize the following energy functions:

$$E(M) = E_{int} + E_{ext}$$

$$E_{int} = \frac{1}{2} \int_0^{t_0} \left[ \alpha \left| \frac{\partial M(s)}{\partial s} \right|^2 + \beta \left| \frac{\partial^2 M(s)}{\partial s^2} \right|^2 \right] ds$$

Where $E_{int}$ is the internal energy, in which $\alpha$ is one weighting parameter that control elasticity and $\beta$ is the other one weighting parameter that control rigidity of the snake curve. With the work of $E_{int}$, the contour curve stretch and bend during deformation. $E_{ext}$ is the external energy that guides the contour toward edges. Xu and Prince improved the term by introducing GVF field $V(x, y) = [u(x, y), v(x, y)]^T$[4], which minimizes the energy function:

$$E_{ext} = \iint \left[ \mu \left| \nabla V \right|^2 + \left| \nabla f \right| (V - \nabla f)^2 \right] dx dy$$

Where $\mu$ is a regularization parameter, and $f$ is the edge map derived from the raw image. The final contour of The GVF snake model is closed, but the shape anomalies make the contour unlike ships.

2.2. Elliptical constraint
Since the GVF snake model just utilizes the image information, the snake contour always seems not like the real ship’s contour. As mentioned earlier, the contour of the real ship has a near-elliptical outline. Therefore, the EC is incorporated into the energy function of the GVF snake to restrict the shape of the snake contour during deformation. Within $x - y$ domain, an ellipse can be expressed as the quadratic polynomial:

$$a x^2 + b xy + c y^2 + d x + e y + f = 0, b^2 - 4ac < 0$$

Where $a, b, c, d, e, f$ are ellipse parameters. The algebraic distance of a point $(x_i, y_i)$ to the ellipse is:

$$D(x_i, y_i) = a x_i^2 + b x_i y_i + c y_i^2 + d x_i + e y_i + f$$

The next, we need to minimize the sum of squared algebra distances to fit the ellipse. Fitzgibbon et al had introduced the equality constraint $4ac - b^2 = 1$ to solve the problem with the inequation constraint $b^2 - 4ac < 0$ which is difficult to solve in general [5]. With the equality constraint, the unique solution of the parameters can be obtained according to the reference [5].

The ellipse can be fit by some points of the snake contour by Fitzgibbon algorithm. The distance from a point to the ellipse can be presented by $|D(M(s))|$, When the point is further away from the ellipse, the value of $|D(M(s))|$ is larger. On the contrary, the value is smaller. When the point is on the ellipse, $|D(M(s))| = 0$. Therefore EC can be applied to the snake curve and $|D(M(s))|$ accords with the variation law of the snake energy function [6]. Thus the energy function of the GVF snake under the EC can be presented as follow:
\[ E(M(s)) = E_{int} + \gamma E_{ext} + \delta E_{EC}, E_{EC} = \int_0^1 |D(M(s))|^2 ds \]  

Where \( E_{int} \) is the energy term of GVF, \( E_{ext} \) is the energy term of EC, \( \gamma \) is weighting parameter that control the strength of GVF field and \( \delta \) is weighting parameter that control the strength of EC field.

The whole deformation should go through some iterations. In each iteration, the GVF snake with EC is explored by two independent operations: (1) The snake curve is fixed and the ellipse parameters are estimated by ellipse fitting. (2) The ellipse is fixed and the snake curve deforms under the GVF with the EC. During deformations, each point of the snake moves under the influence of the external force field and stops when it undertakes balanced forces. When the change rate of the energy function is less than 1%, it is supposed to be converged and the new balance is created. By the way, the shape anomalies are filtered and the target contours are recovered.

3. Discrimination of ship’s bow

In order to reduce the navigation resistance and increase the stability of navigation, the most of ship targets are designed as the bow pointed, stern rules shape characteristics of wide. Especially in warship target, the structure is more obvious. With the improvement of SAR image resolution, the target contour feature becomes more and more clear. The GVF snake model with EC can give us a good target contour which can get good fitting results with least square quadratic polynomial curve fitting.

3.1. The least squares quadratic polynomial curve fitting

Polynomial fitting method is the most commonly used method in curve fitting. The method can be used to represent the nonlinear relationships between the independent variable \( q \) and the dependent variable \( x \).

\[ q(x) = \sum_{i=0}^{N} a_i x^i = a_0 + a_1 x + a_2 x^2 + \ldots + a_N x^N, N \geq 2 \]  

Where \( N \) is the order of polynomial fitting and \( a_0, a_1, \ldots, a_N \) are the parameters of polynomial fitting.

The least square method is a mathematical optimization technique [7]. It matches the best function of the data by minimizing the squared error. In the given function \( y = f(x) \), the values are \( y_1, y_2, \ldots, y_N \) of \( N \) points \( x_1, x_2, \ldots, x_N \), and each point is obtained by the formula \( \sum_{i=1}^{N} (p(x_i) - y_i)^2 = \min \) to obtain the fitting curve.

Considering that it is necessary to compare the curvature of the two ends of the ship’s main shaft, the least squares quadratic polynomial curve fitting can be obtained. When \( N = 2 \), the fitting curve can be expressed as this:

\[ q(x) = \sum_{i=0}^{N} a_i x^i = a_0 + a_1 x + a_2 x^2, N = 2 \]  

The absolute value of the quadratic coefficient of the bow’s end is bigger than the stern’s end. According to that, we can discriminate the ship’s bow.

3.2. The bow discrimination process

The bow discrimination process is shown in figure 1. The first step, we need to input the ROI slice which come from RADARSAT-2 data usually contains only one target, the ROI slice has shown in figure 2(a). The second step, the canny operator is used to extract edge from the ROI slice which is a binary map, the edge map has shown in figure 2(b). One important step is the next step, let the edge to deform under the GVF with the EC and get a good ship’s contour, the ship’s contour under the GVF with the EC has shown in figure 2(c). From the contour, we could calculate some ship’s geometric
parameters, such as length, width, area. For easy to get the least squares quadratic polynomial curve fitting, we could rotate the whole ship’s contour to make its main shaft be perpendicular to the horizontal axis, the rotated contour map has shown in figure 2(d). Next step, the top least squares quadratic polynomial curve fitting is made by top eighth contour points and the second order polynomial fitting coefficient is represented as \( p_{\text{top}} \). Beside, the bottom least squares quadratic polynomial curve fitting is made by bottom eighth contour points and the second order polynomial fitting coefficient is represented as \( p_{\text{bottom}} \). The top-and-bottom fitting curve map has shown in figure 2(e). The final step is to compare the absolute value of \( p_{\text{top}} \) and \( p_{\text{bottom}} \). If the absolute value of \( p_{\text{top}} \) is bigger than the absolute value of \( p_{\text{bottom}} \), the top part of contour is the bow of the ship. Otherwise, the bottom part of contour is the bow of the ship. The discriminated bow map has shown in figure 2(e).

**Figure 1.** Flowchart of the discrimination of ship’s bow

### 4. Experimental Results

According to the method described above, twenty sets of experiments had conducted, and each experiment result had shown that the bow was found correctly. And one of the results is shown in figure 2.

**Figure 2.** Each step’s result map of the discrimination of ship’s bow.(a) The ROI slice.(b) Edge map.(c) Ship’s contour map under the GVF with the EC.(d) Rotated contour map.(e) Top-and-bottom fitting curve map.(f) The discriminated bow map.

Beside this set of map result, we also got fitting curve’s coefficients. For second order polynomial fitting coefficients, \( p_{\text{top}} \) is 0.329 and \( p_{\text{bottom}} \) is -0.248. The absolute value of \( p_{\text{top}} \) is bigger than the absolute value of \( p_{\text{bottom}} \), so the top end of the contour is the bow of the ship. The other nineteen sets of experiments also got the right discrimination results. The whole results of discrimination are shown in table 1. In order to make the compared result of the second order polynomial fitting coefficients more clear, we have highlighted \( p_{\text{top}} \) or \( p_{\text{bottom}} \) which has a bigger absolute value in table 1. Combining the discriminated bow and the true ship’s bow, we get the discrimination result which is right or false. Due to the space impact of this paper, there are only shown four sets of
experimental map results which corresponded to experiment 3, experiment 4, experiment 14 and experiment 18 of table 1. These map results have shown in figure 3.

Figure 3. Four sets of experiment’s map results which corresponded to experiment 3, experiment 4, experiment 14 and experiment 18 of table 1 row by row. And the five columns of experiment’s map results correspond to the ROI slice map, edge map, ship’s contour map under the GVF with the EC, rotated contour map, top-and-bottom fitting curve map and the discriminated bow map column by column.

Table 1. The whole results of discrimination.

| Number of experiment | p_top | p_bottom | True ship’s bow | Discrimination result |
|----------------------|-------|----------|-----------------|-----------------------|
| 1                    | 0.329 | -0.248   | top             | right                 |
| 2                    | 0.252 | -0.491   | bottom          | right                 |
| 3                    | 0.404 | -0.405   | bottom          | right                 |
| 4                    | 0.388 | -0.420   | bottom          | right                 |
| 5                    | 0.078 | -0.146   | bottom          | right                 |
| 6                    | 0.135 | -0.656   | bottom          | right                 |
| 7                    | 0.155 | -0.048   | top             | right                 |
| 8                    | 0.255 | -0.207   | top             | right                 |
| 9                    | 0.166 | -0.045   | top             | right                 |
| 10                   | 0.291 | -0.277   | top             | right                 |
| 11                   | 0.079 | -0.030   | top             | right                 |
| 12                   | 0.045 | -0.031   | top             | right                 |
| 13                   | 0.144 | -0.255   | bottom          | right                 |
| 14                   | 0.097 | -0.103   | bottom          | right                 |
| 15                   | 0.244 | -0.047   | top             | right                 |
| 16                   | 0.142 | -0.243   | bottom          | right                 |
| 17                   | 0.108 | -0.159   | bottom          | right                 |
| 18                   | 0.087 | -0.164   | bottom          | right                 |
| 19                   | 0.083 | -0.150   | bottom          | right                 |
| 20                   | 0.450 | -0.300   | top             | right                 |
5. Conclusion
Thanks to the improvement of image resolution and the method of GVF snake model with EC, we can get a good contour which is similar to real ship’s contour. And that makes it possible to use the least squares quadratic polynomial curve fitting to discriminate the ship’s bow. If we get more information, we could use ship’s bow to predict the future position of the ship. This method still has a serious weakness, which needs a complete and clear contour. But it is difficult to get a good contour when there are a lot of strong noises and interferences in the original SAR image. So, there are still some works need to be done for improving its robustness.

6. References
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