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Ship Detection of Remote Sensing Image on FRHT and Multi-Points Curvature Based Polygon Approximation

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Abstract: One of the most difficult tasks of ship detection is detecting the ship which is docking at the port in remote sensing image. Traditional methods of automatic detection cannot be used to detect the land/water-boundaries, because both the gray values and textural features of a port are similar to those of the ships which are docking at the port. Therefore, ships cannot be accurately detected in this case. In this study, a novel method of land/water-boundaries detection is proposed, which is based on a polygon approximation method by incorporating two techniques, i.e., Fuzzy Randomized Hough Transform (FRHT) and Multi-Points Curvature (MPC). The method considered the feature of human vision that the straight-line of the land/water-boundaries can be detected more accurately and rapidly. With the detection result of land/water-boundaries, ships docking at the port can be accurately detected. The experiment results demonstrate that this method can achieve good result of ship detection.

Key words: Fuzzy Randomized Hough Transform (FRHT), Multi-Points Curvature (MPC), polygon approximation, remote sensing image

INTRODUCTION

Remote sensing is the acquisition of information about an object, which is not needed to make physical contact with the object. The technology of Remote Sensing is widely applied to several fields, such as military and civilian fields. In these applications, aerial sensor technologies are used to detect and classify objects on Earth. In civilian field, a fishery activity monitoring system acts on ship detection and monitoring. In military field, it is essential to detect, classify and recognize some important man-made objects, such as harbors and airports. In addition, damage information of the important man-made object is obtained according to accurate object detection and classification. Ship detection is one of the most difficult techniques in remote sensing image processing (Liao and Wang, 2008; Jin and Chen, 2003; Ouchi *et al*., 2004), which consists of two kinds of ship detection methods. In the first case, when the ships are sailing in the sea, the sea which is regarded as background area has different texture feature from ships. The ships in this case can be detected by simple threshold segmentation or a texture feature based segmentation algorithm. In another case, if ships docked at the port, the background consists of the sea and the port. Both gray values and texture features of the ships are similar to the port. Simple threshold segmentation algorithm and texture feature based segmentation algorithm can not yield good result of object detection in this case.

In recent years, two famous projects for ship detection have been developed in the world. They are Improving Fishers Monitoring through integrating Passive and Active Satellite Based Technologies (MPAST) (Wagner, 2003) and Detection and Classification of Marine Traffic form Space (DECLMS) (Greidanus and Kourti, 2005). In these projects, several systems about ship detection and ship surveillance developed, such as Mast of QinetQ in England, Eldnuset of FFI in Norway, MeosView of Kongsberg in Norway, VDS of JRC in EU, CLS of Kerguelen in France and BOOST in France. Note that only two of them focused on the ship detection in harbour areas. One is Definiens in German (Heynen, 2005), which detected the ships in harbor area in Pan-sharpened images of IKONOS by using eCognition. In this technique, the thematic map is needed to be prepared, which is a MapLayer describing the shape of the port. The other is IRD in France (Olivier, 2006), whose algorithm consists of five steps, i.e., pre-detection, feature

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extraction, feature selection, feature classification and decision. This technique can hardly obtain accurate results of ship detection, because it is difficult to obtain the feature of the ships.

Some ship detection techniques are also developed from the individual researchers. Wang *et al*. (2005) proposed a ship detection method which is based on shape feature of ships. They considered that the Land/water-boundary has a special shape, i.e., a straight line. The object whose shape is semi-ellipse or ellipse alongside the coastline of harbor area can be detected as a ship, which is docking in the port. The disadvantage of this method is that the position of the object is hard to be obtained. Jiang *et al*. (2007) proposed a method of Alterable Included Angle Chain (AIAC)-based curve description to detect the ships in harbour areas. They assumed that the ship in harbour areas is looked like the rice. The ship detection is achieved based on this assumption. However, this method is sensitive to the noisy caused by the low resolution image. Lei and Su (2007) proposed a ship detection technique by incorporating image contour matching method which is based on partial Hausdorff distance measurement. In this technique, the methods of fast distance transform and the pyramid decomposition are used to speed up the Hausdorff distance matching. However, this technique has a couple of disadvantages:

- Hausdorff distance is sensible to rotation and translation. Therefore, it is difficult to obtain the transformation space of the template
- Hausdorff distance is suitable for detecting the occlusion and noisy objects, but it also brings about a lot of false alarms

From the above analysis, we can see that most of the existed technique can hardly accurately detect the ships in the harbor area. In this study, we aim to accurate detect the ships which are docking at the port. In order to obtain the ships in the harbor area, we first separate the ships from the port according to the features of the land/water-boundaries. The method of Fuzzy Random Hough transform (FRHT) is used to obtain the feature of the land/water-boundaries and the method of Multi-points Curvature is employed to obtain the vertexes of the approximation polygons for the land/water-boundaries. As the area which only contains the ships is obtained, we can accurately detect the ships in this area.

METHODOLOGY

The proposed ship detection method: As above mentioned, it is difficult to detect the ships docking the port. It is due to the similar color and texture features

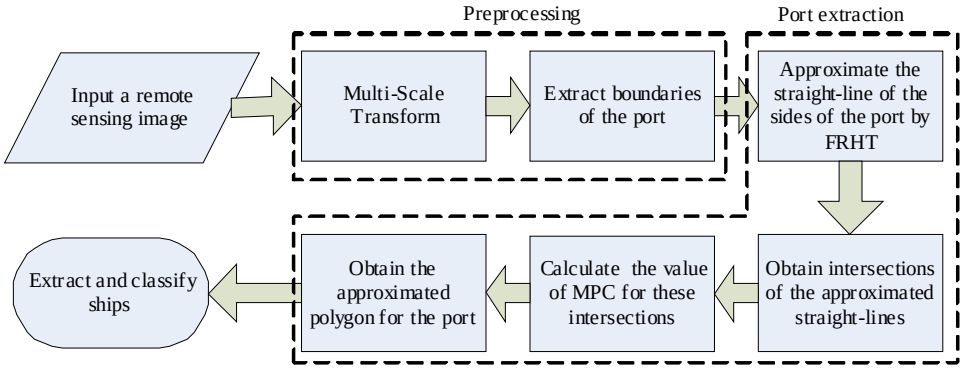
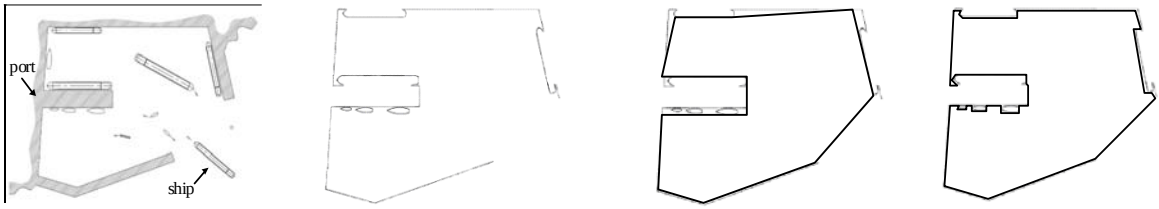


Fig. 1: Flow chart of the proposed ship detection method



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

Fig. 2: Traditional port polygon approximation results: (a) Port image; (b) Edge detection result of (a); (c) Approximation result according to principle (1); (d) Approximation result according to principle (2)

between the ships and ports. We proposed a method for ship detection, which mainly consists of three steps, i.e., Preprocessing, port extraction and ship classification. Figure 1 illustrates the flow chart of the proposed method, which will be introduced in detail as follows.

To speed up the process of ship detection, we employ several methods of preprocessing. The method of multi-scale transform which is based on Gaussian Pyramid is used to resize the input image. To obtain the approximate area of the ship, we use the image segmentation method of watershed. Note that nonlinear anisotropic diffusion filter is used to eliminate the noise. Integral constant is 0.2, the value of propagation function is 2, gradient modulus threshold is 20 and the number of iterations is 5. After image segmentation, the morphology and filling algorithms are used to eliminate the noise obtained from ship image segmentation will be more or less eliminated. Then, the boundaries of the segmentation result can be extracted.

Port extraction: Considering that the shape of the port is similar to an irregular polygon and each edge of this polygon is similar to a straight line. We propose a polygon approximation method to automatically extract the port area. Note that there are two traditional methods of polygon approximation for a closed digital curve (Wang *et al*., 2009), i.e.,

- Given the tolerance error ε of the approximation polygon, the polygon is approximated with the minimum number of vertices
- Given the number of vertices of the approximation polygon, the polygon is approximated with the minimum approximation error

Figure 2 shows the example for the two methods. Figure 2a is a simulated image of port area, where there are several ships docking at the port. After preprocessing (i.e., multi-scale transformation, segmentation and denoising), edge detection result is obtained shown in Fig. 1b. It can be seen that some edges of the image are not standard straight-lines. With the edge detection result, the vertices of the port can not be easily obtained. Approximating the port polygon with principles (1) and (2) will obtain the results shown in Fig. 2c and d, respectively. From these results, we can see that both principle (1) and (2) are not suitable for the port polygon approximation. It is due to the reason that the traditional segmentation method can not separate the ships and port. Therefore, traditional principles and methods for polygon approximation can not be used to approximate the polygon of the port.

In this study, we propose a novel port extraction method which consists of two steps, i.e., approximating edge of the port by using the method of FRHT and approximating port polygon with the approximated edge by using the method of MPC.

Edge approximation for the port by FRHT: The shape of the port is similar to an irregular polygon and each edge of the port is similar to a straight-line. Several techniques are developed to approximate the straight-line, such as Hough Transformation (HT) (Hough, 1962), Fuzzy HT (FHT) (Xu *et al*., 1990), Random HT (RHT) (Vassilios and Ioannis, 1997) and Fuzzy RHT (FRHT). .In this paper, we incorporate FRHT to approximate the edge of the port. Note that FRHT is the combination of FHT and RHT, which is efficient to detect the shape of the object image with noise at low computational cost.

Fuzzy randomized Hough transform: We first introduce the technique of FRHT. Zadeh (1965) proposed a fuzzy set as an extension of classical sets, which was defined as a subset of the universe of discourse X. The characteristic function of X is extended to the membership functions $\mu_A: X \to [0,1]$ with a range in the unit interval. The value 1 represents that x is an element of A and the value 0 is the opposite. The value between 0 and 1 represents the intermediate membership. Hence, a fuzzy set can be characterized by the universe of discourse and the membership function $A = \langle X, \mu_A \rangle$.

There are some basic concepts of fuzzy sets (Klir and Folger, 1988) as follows:

- α -cut. If there is at least a number "1" which is the membership function of a fuzzy set, this fuzzy set is a normal α -cut. It can be defined as:

  $$A\ \alpha = \{x \mid \mu_A(x) \geq \alpha\} \quad (1)$$

  the 1-cut is called the core. And the strong α-cut can be defined as:

  $$A\ \alpha = \{x \mid \mu_A(x) > \alpha\} \quad (2)$$

  And the strong 0-cut is called the support set.
- A convex fuzzy set A is still a fuzzy set that every α cut of A is convex. A convex normal fuzzy set of real numbers is called a fuzzy number. When there is only one point in its core, the fuzzy number is defined as a strict fuzzy number.

- Possibility measures. It can be defined as:

  $$\forall A, B \in p(X): g_p(A \cup B) = \max\{g_p(A), g_p(B)\}$$

  According to the theory of the possibility distribution, the membership function can be determined by the Resolution Principle:

$$\mu_A = \max_{\alpha \in (0,1]} \{\alpha \chi_{A\alpha}\} \tag{4}$$

Thus, the membership function of A is defined as the maximum value of the membership degrees attached to its α-cut. It can be defined as:

$$A = \max_{\alpha \in (0,1]} \{\alpha A_\alpha\} \tag{5}$$

If let a strict fuzzy point represent every point in the original space of an image, its core will be the original point in this image. The membership function, that is attached to the fuzzy point should be isotropic, i.e., all of its α -cut are disks. After transforming, every ordinary point in the image will map into a set of lines or curves in a parameter space. According to the Resolution Principle, there are some sets in which the union is defined as the α -cut of the image that is the α-cut of the original fuzzy point. Then, the membership function of the transformed image is defined as the maximum value of the membership degrees that are attached to the images of the α -cuts of the original image points. If H denotes FRHT from the original X space to the parameter space Π, a fuzzy point A can be obtained from:

$$H(A) = \max_{\alpha \in (0,1]} \{\alpha \bigcup_{x \in A\alpha} H(x)\} \tag{6}$$

According to the probability theory, the accumulative value of the parameter space $f(\rho,\theta)$ is determined by the density of transform sets. Every point on curve P within the range of distance R from (x, y) will have more or less effect on the total density value. Therefore, the transform of a point (x, y) can be defined as the strongest single piece of evidence in which the shape approaches to (x, y). If the distance between the nearest point on P and (x, y) is d, then the membership degree of P which belongs to the transform of (x, y) is w (d). The other points in that the distances are more than R contribute nothing to the accumulative value.

While the usage scope of RHT is extending to fuzzy points, these membership degrees are accumulated along the shape of each parameter P, just as adding membership degree in the original RHT. Analytically, this summation would be recognized as integration and for theoretical argument, it can be treated as such. In deed, just like ordinary RHT, in discrete original space and parameter space Π, the results of accumulating need not to be scaled to close to the results of integral. It only needs to seek local maximum value in parameter space Π.

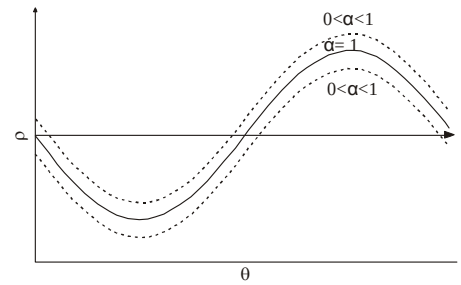


Fig. 3: α-cut of FRHT of a single point

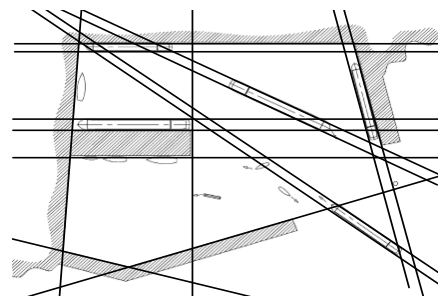


Fig. 4: Edge-segment approximation results for the port by using FRHT

Straight-line detection by using FRHT: According to the Resolution Principle, the membership function of the transform result of a fuzzy point can be reconstructed. An individual circle which has a parameter Ψ can be used to represent an α -cut, with points $x = x_{0,1} + r\cos\Psi$ and $y = y_{0,1} + r\sin\Psi$. These points are mapped into the point (ρ,θ) in parameter space Π, defining a curve in parameter space Π:

$$(x_0 + r\cos\psi)\cos\theta + (y_0 + r\sin\psi)\sin\theta = \rho \tag{7}$$

If tan θ Ψ, then $\theta = \Psi$ or $\Psi + \pi$ and(sin Ψ,cos Ψ) = ± (sin θ, cos θ). It has

$$\begin{aligned}\rho &= (x_0 \pm r\cos\theta)\cos\theta + (y_0 + r\sin\theta)\sin\theta = \\ &x_0\cos\theta + y_0\sin\theta \pm r\end{aligned} \tag{8}$$

Thus, the points of disk map to envelop in parameter space Π with the range of distance $\pm r$ along the ρ direction. As shown in Fig. 3.

Figure 4 shows the example of edge approximation by using FRHT. The original image is shown in Fig. 2(a). From Fig. 4, we can see that there are 16 straight-line are detected while 9 of them are real edge of the port. Next, the technique of MPC is proposed to eliminate the false detected straight-lines.

Port polygon approximation based on FRHT and MPC: As there are some false detected straight-lines

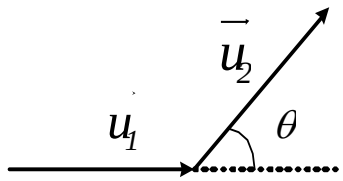


Fig. 5: Difference in directions of two vectors

obtained by FRHT, in this section, we aim to eliminate the false detected straight-lines and obtain the approximated polygon for the port. The polygon approximation is one of the most important techniques for object shape detection (Asif, 2008; Zhang *et al*., 2008). The traditional method of object shape detection mainly consists of two steps, i.e., extracting boundaries of the objects and approximating the polygon for the extracted boundaries. The approximation principle is that minimizing approximation error while reducing the computational cost as much as possible.

According to this principle, we propose a port polygon approximation method based on the technology of MPC and the results of FRHC. The definition for MPC is given by:

$$\Delta\theta = \cos^{-1}\frac{\vec{u}_i.\vec{u}_{i+n}}{|\vec{u}_i||\vec{u}_{i+n}|} = \cos^{-1}\frac{(x_i - x_{i-n})(x_{i+n} - x_i) + (y_i - y_{i-n})(x_{i+n} - x_i)}{\sqrt{[(x_i - x_{i-n})^2 + (y_i - y_{i-n})^2][(x_{i+n} - x_i)^2 + (y_i - y_{i+n})^2]}} \quad (9)$$

If $i = 1$, MPC is degenerated to an ordinary curvature. Note that the mathematical definition of an ordinary curvature is $d\theta/ds$ (Rosin, 1997), where θ is the angle between the positive x-axis and the tangent vector of the curve. A continuous approximation of $d\theta/ds$ can be calculated by using the definition of ordinary curvature directly. But a discrete approximation of $d\theta/ds$, which is computed for evenly spaced points, depends linearly on the angle $\Delta\theta$ between the two vectors $\vec{u}_i = (x_i - x_{i-n}, y_i - y_{i-n})$ and $\vec{u}_{i+n} = (x_{i+n} - x_i, y_{i+n} - y_i)$, as shown in Fig. 5.

Note that the boundary of the port is not a standard polygon and each side of the port is not a standard straight-line but an irregular curve. The values of the ordinary curvatur es for the vertices of the port fluctuate irregularly. However, the values of MPC for the vertices of the port polygon are in a certain range. Therefore, the proposed polygon approximation method is based on the technique of MPC, which mainly consists of five steps, i.e.,

Step1: Obtaining the x and y coordinates of the intersections that are obtained from the straight-lines detected by FRHT

Step2: Detecting the points of the boundaries that are close to the intersections and recording the coordinates of these points

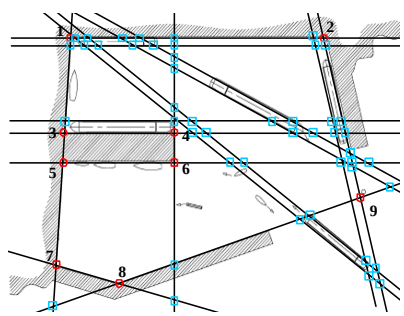
Step3: Calculating the value of MPC of these points that are obtained from Step 2

Step 4: Finding out the points whose MPC is larger than the threshold T_{MPC}, these points are regarded as the vertices of the port polygon

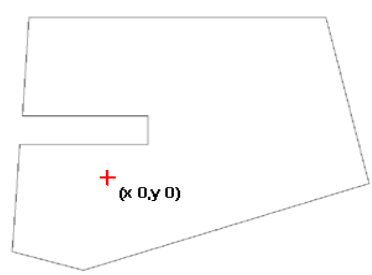
Step 5: Connecting these points that are obtained from Step 4 in clockwise\counter-clockwise of boundaries. Then the approximate polygon of the port is obtained

Figure 6 shows the example of the port polygon approximation. After the approximated straight-lines are obtained by using FRHT (Fig. 4), 55 intersections are extracted from these straight-lines. Where, 9 of them are the vertices of the port polygon, which are denoted by red circles shown in Fig. 6a. We extract these vertices using MPC and obtain the approximated polygon shown in Fig. 6b by the proposed polygon approximation method.

Ship classification by shape analysis: After the approximated port polygon has been obtained, the ships

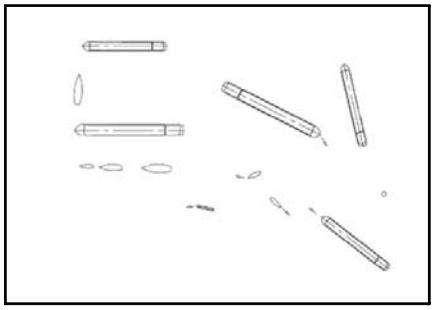


(a)

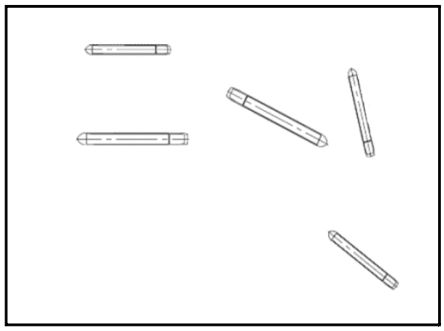


(b)

Fig. 6: (a) Mark result, (red points are vertices of the port polygon), (b) Port polygon (Red cross is the center)



(a)



(b)

Fig. 7: Ship classification by shape analysis, (*a*) Ships are extracted from the water area, (*b*) Ships classification results

can be separated from the land/water-boundaries Fig. 7a by simple threshold or texture algorithm. It is due to the reason that both gray value and texture of the ship are different from the water. Then we can classify these ships by shape analysis. The ratio of length to width for the ship is used to exclude noise-object which is not the ship. The classification results are shown in Fig. 7b.

EXPERIMENTAL RESULTS

In this section, we evaluate the proposed method using a set of real data. The comparison of the proposed method with the state of the art method is also provided.

Evaluation of the proposed method: To evaluate the proposed method, we use a real remote sensing image (Fig. 8) of size 1796 70 from Google Earth with 1-m spatial resolution. For the image preprocessing, the Gaussian Pyramid is used to resize the original image to the image of size 899 85. Nonlinear anisotropic diffusion filter is used to eliminate the noise, where integral constant is set to 0.2, the value of propagation function is set to 2, gradient modulus threshold is 20 and the number of iterations is 5. The method of watershed is used to segment the port image into several areas. The port area

Fig. 8: The port remote sensing image

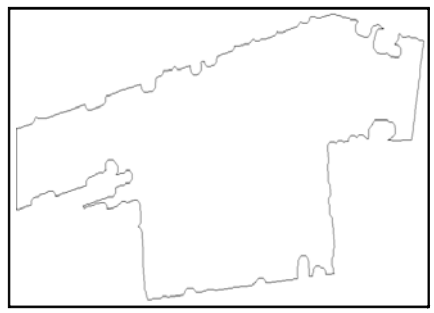
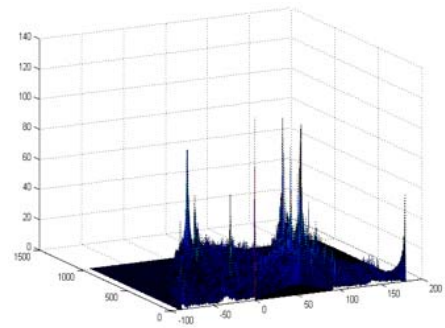


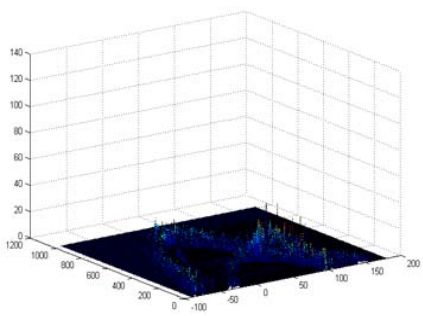
Fig. 9: Boundaries of segmentation result

is the biggest area selected from the result of image segmentation. The morphology and filling algorithms are then used to eliminate the noise obtained from image segmentation. Finally, the boundaries of the segmentation result is obtained, which is shown in Fig. 9.

After preprocessing and boundaries extracting, FRHT is used to detect approximate straight-lines from the extracted boundaries. Note that there are 9 sides for the port polygon in this image. According to the technique of FRHT, there are several peaks shown in Fig. 10a, which can represent the local maximum values of accumulation in parameter space of FRHT. Note that each peak corresponds to a straight-line in the original space. In Fig. 10a, the number of the peaks is more than 9. In order to select the candidate side of the port polygon, we set a threshold T_{ac} of accumulation. The straight-line whose value of accumulation in the parameter space is larger than T_{ac} can be selected as candidate side of the port polygon. In this paper, the value of T_{ac} is set to 20 in our empirical study. Figure 10b shows the thresholding result of Fig. 10a using the threshold T_{ac}. We can see that most of the peaks are selected which corresponding to the candidate sides of the port polygon. Note that there are 13 peaks in the parameter space are selected, which correspond to the approximated straight-lines in original image shown in Fig. 11. However, 4 of them are not the approximated straight-lines for the side of the port polygon. Next, they will be eliminated by using the MPC based method.



(a)



(b)

Fig. 10: Accumulation of FRHT in a parameter space, (a) is the initial accumulate of FRHT, (b) is the thresholding result of, (a) using the threshold T_{ac}

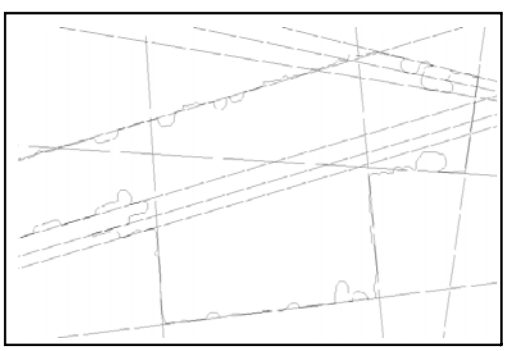


Fig. 11: The straight-lines which correspond to the peaks in the parameter space

The MPC based method is used to eliminate these false approximated straight-lines and obtain the approximated polygon of the port. Firstly, the intersections of the approximated straight-lines are obtained, which are shown in Fig. 12. There are 37 intersections, which consists of two classes as follows: 1) the intersections which are existed in the boundaries of the port polygon, such as the intersections 2, 3, 4, 6, 7, 9, 10, 13, 14-16, 18, 19, 20, 29, 30, 31 and 37 shown in Fig.12; 2) the intersections which are not existed in the

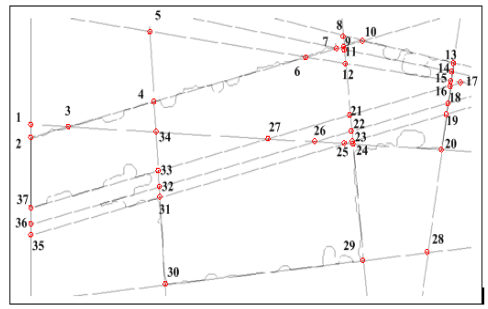


Fig. 12: The intersections (the red circles) of the approximated straight-lines

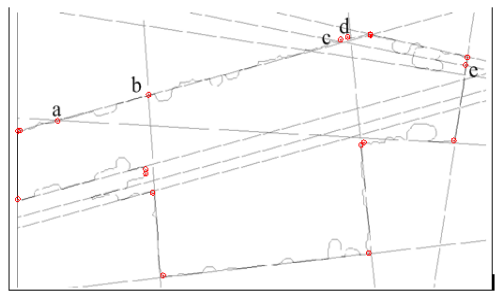


Fig. 13: Candidate corners obtained after filtering by MPC method

boundaries of the port polygon, such as the intersections 1, 5, 8, 11, 12, 17, 21-28, 32, 33, 35 and 36 shown in Fig. 12. The intersections of the first class contain the potential vertices, such as 2, 10, 13, 20, 29, 30, 31 and 37. The intersections of the second class also contain the potential vertices, such as the intersections 23, 24 and 33 shown in Fig. 12. Note that the port is usually not a standard polygon and the sizes of the polygon are usually not the standard straight-lines. Therefore, there are some intersections of the second class which are the vertices of the approximated port polygon, but keep a small distance from the boundaries, such as intersections 23, 24 and 33 shown in Fig. 12. These intersections which are the potential vertices, can be selected in the following steps, i.e., we first calculate the distances d between every intersections of the approximated straight-lines and the boundaries of the port. Then, we select the intersections of the second class whose value of d is larger than the threshold d_T as the candidate vertices. d_T is set to 25 in our empirical study in this paper. The candidate vertices denoted by the red circles are shown in Fig. 13, which consists of two kinds of intersections, i.e., the intersections of the first class and the selected intersections of the second class.

Next, we compute the values of MPC of the candidate vertices. Where the parameter i is set to 30 in formula (9) and the threshold of MPC is set to 0.1. The

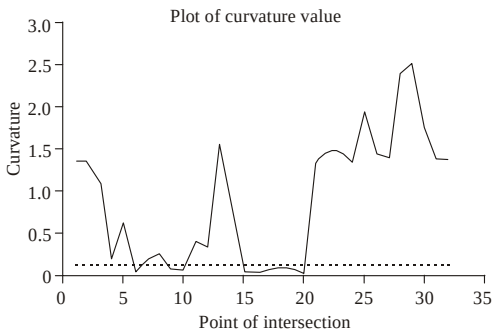


Fig. 14: The value of MPC of the intersections

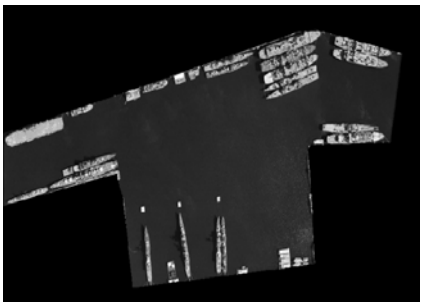


Fig. 15: The water area

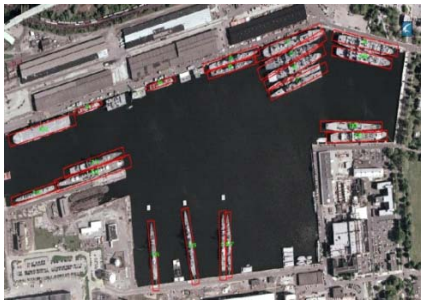


Fig. 16: Ship detection result

intersections whose values of MPC are larger than 0.1 can be selected as the vertices of the port polygon. As shown in Fig. 13, the intersections a, b, c, d and e which are not the vertices are eliminated according to their MPC values shown in Fig. 14, where the red dashed line represents the threshold of MPC. Finally, the vertices are connected in clockwise or counter-clockwise of the boundares and the port polygon is obtained.

As the approximated polygon of the port has been obtained, the water area can be extracted, which is shown in Fig. 15. The ships in this water area can be easily detected according to the ratio of length to width and the size of the ships. The result of ship detection is shown in Fig. 16 and the detection rate is up to 90%. As shown in Fig. 17, we also provide the detection rate and false alarm rate with different values of MPC. In particular, we can

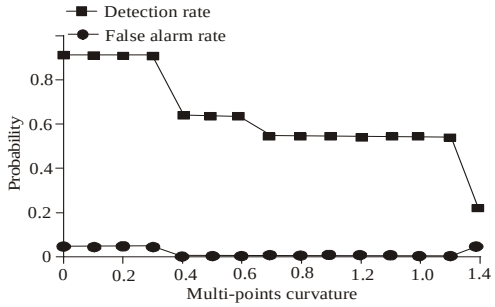


Fig. 17: Variation of detection rate and false alarm rate

(a)

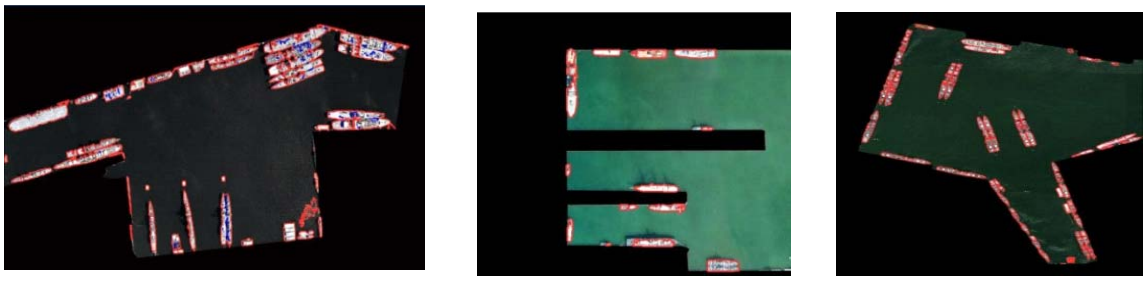
(b)

(c)

Fig. 18: Five raw images

see that the detection rate is high when the value of MPC is smaller than 0.3, but the detection rate decreases sharply when the value of MPC is larger than 0.3. False alarm rate changes slowly during the variation of the value of MPC.

Comparison with the other method: To evaluate the performance of the proposed method on ship detection, we compare the proposed method with the state of the art method. As shown in Figure 18, three real remote sensing



(a) (b) (c)

Fig. 19: Detection results of ecognition's method

(a) (b) (c)

Fig. 20: Port approximation and ship detection results of this paper's method

Table 1: False alarms, missed alarms and total errors (in number of pixels and percentage) resulted from different methods of ship detection on optical satellite images

	Detection rate		False alarm rate	
Experiments	Method (Ursula *et al*., 2004)	Proposed method	Method (Ursula *et al*., 2004)	Proposed method
1	1	0.95	0.15	0
2	0.93	0.86	0	0
3	1	0.96	0.07	0.03
Average	0.98	0.92	0.07	0.01

images of size 1897×970 599×543 and 2236×2768 are given, which are captured from Google Earth with 1-m resolution. Note that these images are captured from three different ports and there are many ships with different sizes docking at each port. The method of eCognition (Wang *et al.*, 2004; Ursula *et al*., 2004), is used to compare with the proposed method. eCognition is a well known software for image analysis, which is developed by the company of Definiens. It can achieve good results of ship detection in the projects of MPAST and DECLMS. However, the thematic maps of the land/water-boundaries must be prepared manually in this method, which significantly affects the detection speed.

The result of ship detection for eCognition method and the proposed method are shown in Fig. 19 and 20 respectively. From Fig. 19, we can see that most of the ships in the images are detected, but some objects which are similar to the ships are falsely detected. Note that some ships connected each other can be hardly detected by using eCognition method. Our proposed method can achieve better result of ship detection, but there are some miss alarms which are created by the approximation error for the polygon approximation. Note that the yellow polygons in Fig. 20 are the results of the port approximation. To compare the ship detection with recognition results in quantitative measure, the values of detection rate and false alarm rate of the two methods are computed which is shown in Table 1. The average values of detection rate and false alarm rate of eCognition are 98 and 7%, respectively, whereas, the average values of detection rate and false alarm rate of our proposed method are 92 and 1%, respectively. The detection accuracy of the proposed method is comparable to the detection accuracy of eCognition method. Note that the proposed method is fast and automatic, which can perform ship detection without preparing thematic maps. On the contrary, the thematic maps should be prepared manually for eCognition method, which is slower and semi-automatic.

CONCLUSION AND FUTURE WORK

In this study, we proposed a novel method for ship detection in harbor area. A straight-line approximation method is developed to extract the sides of the port by incorporating the techniques of FRHT. The value of MPC is used to eliminate the false alarms for the straight-line approximation of the sides of the port and obtain the approximated polygon of the port. Ship detection can be easily performed based on the result of the approximated polygon. Comparison with the state of the art method demonstrates that the proposed method can achieve good result of ship detection.

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REFERENCES

Asif, M., 2008. Optimized polygonal approximation by dominant point deletion. Pattern Recogn., 41(1): 227-239.

Greidanus, H. and N. Kourti, 2005. DECLMSWPS status and Plans. The Fifth Meeting of the DECL MS Project, Farnborough, UK.

Heynen, M., 2005. Coastal Mapping and Ship Detection from VHR Satellite Imagery. The Fifth Meeting of the DECL MS Project, Farnborough, UK.

Hough, P.V.C., 1962. Method and Means for Recognizing Complex Patterns. U.S. Patent 3069654.

Jiang, L.B., Z. Wang and W.D. Hu, 2007. An AIAC-based inshore ship target detection approach. Remote Sensing Technol. Appl., 22(1): 88-94.

Jin, M.K. and K.S. Chen, 2003. The application of wavelets correlate for ship wake detection in SAR images. IEEE T. Geosci. Remote, 41(6): 1506-1511.

Klir, G.J. and T.A. Folger, 1988. Fuzzy Sets, Uncertainty and Information. Prentice-Hall, London.

Lei, L. and Y. Su, 2007. An inshore ship detection method based on contour matching. Remote Sensing Technol. Application, 22(5): 622-627.

Liao, M.S. and C.C. Wang, 2008. Using SAR images to detect ships from sea clutter. IEEE Geosci. Remote S,. Letters, 5(2): 194-198.

Olivier P., 2006. Optical Data for Ship Detection. The Sixth Meeting of the DECL MS Project. Ispra, Italy.

Ouchi, K., S. Tamaki, H. Yaguchi and M. Iehara, 2004. Ship detection based on coherence images derived from cross correlation of multi look SAR images. IEEE Geosci. Remote S., 1(3): 184-187.

Rosin, P.L., 1997. Techniques for assessing polygonal approximations of curves. IEEE T. Pattern Anal., 19(6): 659-666.

Ursula, C.B., H. Peter, W. Gregor, L. Iris and H. Markus, 2004. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. ISPRS J. Photogramm. Remote S., 58: 239-258.

Vassilios, C. and P. Ioannis, 1997. Fuzzy cell Hough transform for curve detection. Pattern Recogn., 30(12): 2031-2042.

Wagner, M.J., 2003. From ships to shores to satellite images. Sea Technol., 4: 38-41.

Wang, Z.Y., W.X. Wei and S.H. Zhao, 2004. Object-oriented classification and application in land use classification using SPOT-5 PAN imagery. In Proceedings of IEEE International Geosciences Remote Sensing Symposium (IGARSS), pp: 3158-3160.

Wang, M., J.C. Luo and D.P. Ming, 2005. Extract ship targets from high spatial resolution remote sensed imagery with shape feature. Geometrics Inf. Sci. Wuhan Univ., 30(8): 685-688.

Wang, B., H.Z. Shu and L.M. Luo, 2009. A genetic algorithm with chromosome-repairing for min - # and min - ϵ polygonal approximation of digital curves. J. Vis. Commun. Image R., 20(1): 45-56.

Xu, L., E. Oja and P. Kultanen, 1990. A new curve detection method: Randomized hough transform. Pattern Recogn. Lett., 11(5): 331-338.

Zadeh, L.A., 1965. Fuzzy sets. Inf. Control, 8(3): 338-353.

Zhang, K., J.B. Lu and G. Lafruit, 2008. Scalable stereo matching with Locally Adaptive Polygon Approximation. In Proceedings of 15th IEEE International Conference, 12-15 October, pp: 313-316.