Research on Radar Target Detection Method Based on the Combination of MSER and Deep Learning

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Abstract. Aiming at the problems that arine radar cannot automatically output targets and is difficult to deal with false echoes, this paper adopts the method combining MSER and deep learning to detect radar echoes based on the theory of radar echo image processing. Through the off-line radar echo data and the real-time test at the radar station, the method can automatically output radar targets, and the detection rate is high. Therefore, this method can be used as a reference for radar target detection algorithm research and engineering application.

Keywords: Radar echo · MSER · Deep learning · Target detection · Contour extraction

1 Introduction

Marine radar is divided into navigation radar and traffic management radar, its main function is to achieve target detection and target tracking. Navigation radar is mainly to achieve navigation and collision avoidance functions. For ship pilots, radar is equivalent to their "eyes". Shore-based radars are generally installed at ports or beaches to monitor and assist safe entry of ships. Radar has all-weather fairness. According to IEC62388, X-band (9.2–9.5 GHz) and S-band (2.9–3.1 GHz) are mainly used in the field of navigation. At present, marine radar uses traditional signal processing methods to achieve target detection which requires manual adjustment of parameters such as thresholds to obtain object information. There are cases where clutter is detected as a target or small targets are filtered out as a result of the difference of the way of each person's adjustment. It affects the accuracy of radar target detection leading to inaccurate provision of accurate and reliable target information for users [1]. Therefore, the realization of automatic detection of radar targets has important practical significance.

The function of radar automatic target detection can be implemented according to the existing engineering design requirements, without changing the equipment hardware, and ensuring that the data processing time is less than the antenna rotation period. This paper takes a method that combines pre-detection and deep learning which is described in Fig. 1 below:
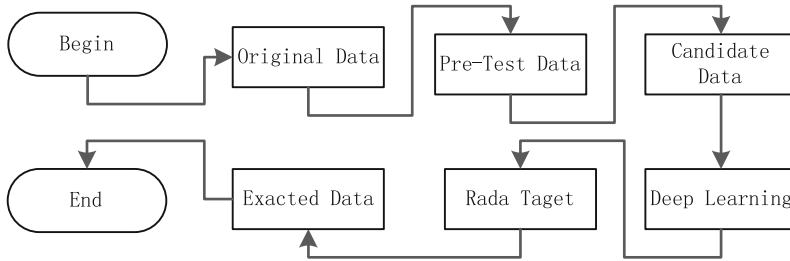
Fig. 1. Data processing flow chart

As shown in Fig. 1, this paper first pre-detects the original radar echo data to obtain the candidate area, then uses deep learning to detect the candidate target to obtain the target, and finally extract the contour of the target.

2   Pre-detection

Maximally Stable Extremal Regions (MSER) was proposed by J. Matas in 2004 based on the watershed concept [2]. The basic idea of MSER is to select a series of thresholds from 0 to 255 to perform binary segmentation of the image and the gray value below the set threshold is 0, but higher than or equal to the set is 255. The image will form a closed region as the threshold increases from 0 to 255. The maximum extremal region is the region with the smallest area change within a certain threshold range [3]. This paper uses method of MSER as pre-detection to obtain candidate target regions.

The mathematical definition of MSER is [4]:

$$q(i) = |Qi + \triangle - Qi - \triangle|/Qi \tag{1}$$

where Qi is the connected region when the threshold is i, $\triangle$ is the variation of gray threshold value and q(i) is the rate of change of Qi when the threshold is i. When q(i) is the local limit value, Qi is the maximally stable extremal region.

In addition, this paper separately counts the echo sizes of S-band and X-band long, medium and short radar pulses corresponding to different ships. The radar echo size is limited to: width range [3, 200], height range [3, 60]. The pre-detection targets can be further screened by comparing the stable region with the echo size.

3   Deep Learning

Deep Learning refers to an algorithm that uses a larger number of layers of neural network structures to complete training and prediction. It has been widely used in machine vision such as pedestrian detection, face detection, remote sensing image detection, and medical image processing. This paper adopts the ResNet (Residual Network) network, which is a residual school framework proposed by K. He et al. [5] (Fig. 2).
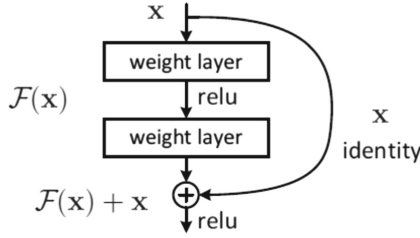
Fig. 2. Residual mapping for ResNet

The residual structure can be simplified as follows [6]:

$$x_{l+1} = x_l + F(x_l, W_l) \tag{2}$$

The expression of the L feature of any layer unit is:

$$x_L = x_l + \sum_{i=l}^{L-1} F(x_i, W_i) \tag{3}$$

If ξ represents the loss function according to the chain rule, we can get:

$$\frac{\partial \xi}{\partial x_l} = \frac{\partial \xi}{\partial x_L} \frac{\partial x_L}{\partial x_l} = \frac{\partial \xi}{\partial x_L} \left(1 + \frac{\partial}{\partial x_l} \sum_{i=l}^{L-1} F(x_i, \omega_i)\right) \tag{4}$$

Based on the above and open source related theories, the dataset used in this paper comes from the original echo data recorded by navigation radar and shore-based radar, then the sample data is labeled and trained. Among them, the sample labeling tool is labelImg, the training environment: CPU is Intel(R) Core(TM) i7 8200X, GPU is GeForce RTX2080Ti, operating system is Ubuntu18.04 LTS, Cuda10.2, and finally the network model is trained with.caffemodel file.

4   Experiments and Results

Based on the above theoretical discussion, the data processed by MSER is used as the input of deep learning ResNet, and then the output radar target is detected. Finally, the offline radar echo data and real radar sites are used to conduct experiments to statistically analyze the number of ship targets within 8nm, target detection rate, false detection rate, and missed detection rate. The method described above is used to process the original radar echo data, and select 8 different radar scene data for testing and analysis. The details are shown in Table 1 below.
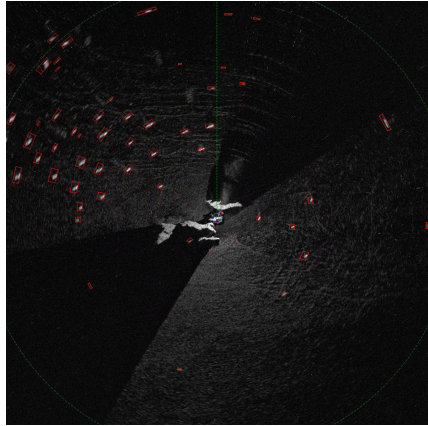
Fig. 3. Zhuhai Dangantou radar station experiment

Figure 3 shows the results of the actual measurement at the Zhuhai clubhead radar site, which draws a rectangular frame on the original radar echo image to represent the detected target.

Table 1. Statistical table of real scene test results

No	Data	Target	Detection	Missed	False	Missed detection rate	False detection rate	detection rate
						Missed/Target	False/Target	Detection/Target
1	Scene 1	87	86	1	4	1.15%	4.60%	98.85%
2	Scene 2	36	34	2	7	5.56%	19.44%	94.44%
3	Scene 3	83	77	6	1	7.23%	1.20%	92.77%
4	Scene 4	53	51	2	0	3.77%	0.00%	96.23%
5	Scene 5	62	56	6	9	9.68%	14.52%	90.32%
6	Scene 6	62	61	1	11	1.61%	17.74%	98.39%
7	Zhuhai Dan club head	119	114	5	1	4.20%	0.84%	95.80%
8	Zhuhai Hebao Island	120	111	9	1	7.50%	0.83%	92.50%

As shown in Table 1, scenes 1 to 6 are the echo data scenes recorded by the navigation radar, and scenes 7 to 8 are the measured scenes at the Zhuhai Dangantou and Zhuhai Hebao Island sites. In Table 1, the number of targets is the number of ships and other targets within 8 nautical miles, the number of detected targets is the number of targets detected by the algorithm processing, the number of missed detections is the number of targets not detected by the algorithm, and the number of false detections refers to the number of false detections of clutter as the target by the algorithm. This method has a certain missed detection rate and false detection rate, but its detection rate is above 90%.

5   Target-Based Contour Extraction

For the radar target detected by MSER+ResNet, use OpcnCV to extract the contour of the radar target of which OpcnCV (Open Source Computer Vision Library) is an open source computer vision library [7]. This paper uses the findContours() function in OpenCV to extract the contours in the binary image, and then uses the drawContours() function to draw the radar target echo on the image attributes, and fill it with a custom color, as shown in Fig. 4 below.
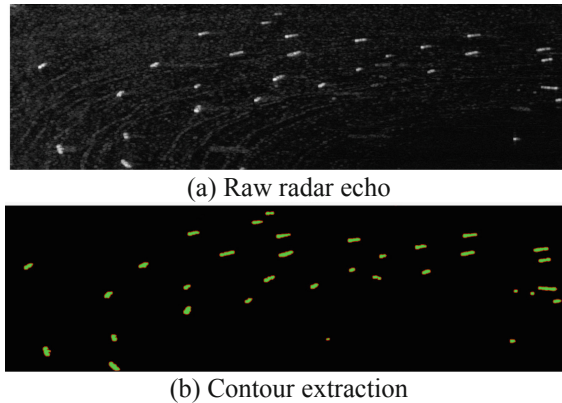

(a) Raw radar echo

(b) Contour extraction

Fig. 4.   Radar raw echo and Contour

As shown in Fig. 4, Fig. 4(a) is the original echo image, and Fig. 4(b) is the target echo image after contour extraction. It can be seen from this that if a high detection rate is ensured, this method has clutter suppression and can improve the visualization effect.

6   Conclusion

Based on image processing related theories, this paper uses a combination of MSER and ResNet to process radar echo data, and tests on offline data and radar sites respectively. In a radar antenna rotation period, proposed method can effectively process a frame of echo data, the detection rate is above 90%, and the radar target is automatically output. And extract the contour based on the radar target echo and customize the fill color to increase the visualization effect of the radar echo. It has certain reference significance to the research and engineering application of radar target detection algorithm.

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