Automatic Detection of the Underwater Stationary Artificial Torpedo-shaped Target Based on SAS Image

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Abstract. Aiming at the problems of speckle noise, seafloor background scattering interference and lack of texture feature in SAS images, an underwater torpedo-shaped artificial target detection algorithm based on Meanshift filtering and Ostu algorithm was proposed. Firstly, based on the image characteristics, the Meanshift filtering algorithm is used to confirm an appropriate threshold to achieve a smoothing effect, and eliminate the strong background speckle noise. Secondly, Ostu algorithm is used to perform binarization according to the histogram statistical information after image gray-scale. Finally, the Region growth method is used to find and eliminate the large and unrelated white areas, meanwhile, fill the holes in the target to obtain a relatively complete target contour. The experimental results show that the algorithm is simple, has a strong ability to overcome the background noise. The automatic detection of the target is accurate. The algorithm is stable with a strong engineering value.

1. Introduction

Acoustic detection technology is the main underwater detection technology. As a high resolution underwater acoustic imaging equipment, synthetic aperture sonar (SAS) plays an important role in underwater exploration, underwater target detection and recognition. For civilian use, it can search for artificial targets such as crashed aircraft, sunken ships, underwater structures and natural targets. In the military, it can detect underwater vehicles, mines and other military targets. An important task of underwater target detection is to carry out underwater artificial target detection and recognition based on sonar image. Before the detection and recognition of the underwater sonar image, it is necessary to extract the target feature. And the target contour is one of its important features.

The basic imaging principle of SAS is also based on acoustic scattering. Sending the pulse sound waves towards the seabed, the sound waves hit the bottom of the sea, sunken objects. Then the back scatter signal is received and processed by the receiving system. The imaging resolution can be greatly improved by the virtual synthetic aperture produced through the movement of the carrying platform. And then the synthetic aperture sonar image (sound map) of the sea bottom is formed¹. The pixel grayscale of the SAS image depends on the strength of the sound reflected by the ocean floor material. Generally, for the hard, rough and convex seabed, the echo is more stronger. For the soft, smooth and depressed seabed, the echo is weaker. The blocked seabed does not produce echo. The farther the distance is, the weaker the echo will be.
In target detection, the sound map can be usually divided into the target highlight area, the target shadow area and the underwater background area. Previous scholars have explored the automatic extraction technology of underwater sonar image for many years. Reed S. et al. used the improved snake model to extract sonar image contour. Liu Zhuofu et al. proposed a snake model based on the structure of cellular neural network to extract the target contour. However, the method in the literature is not satisfied for the segmentation of the discontinuous, porous and irregular underwater objects. Chen liqiang et al. used Canny operator to extract the mine contour for the use of mine classification and recognition. Wang xingmei used the method of MRF to extract the sonar image contour, but the results contained more noise point. Luo jinhua et al. extracted the profile of side-scan sonar image based on mathematical morphology and Ostu law. But the processing object was the side-scan sonar image data. The resolution was limited, so the segmentation result was not accurate.

In this paper, a Meanshift filter combined with Ostu algorithm is proposed to detect the underwater stationary artificial torpedo-shaped target based on SAS image. The idea of the algorithm is simple, with a strong ability to overcome the background noise. The target extraction contour continuity is accurate. The proposed method has strong engineering practice value, especially with good effect for torpedo-shaped targets. The algorithm flow chart is in figure 1.

2. Target and Image Feature Analysis

In SAR images, there are three main areas: light area, sound shadow and underwater background. The main reason for the change of sonar image gray scale is the sound wave reflecting strength of the underwater material. The metal objects can produce a strong echo and form a brighter point. Sound-absorbing materials, such as mud, can produce weak echoes and form darker points. The part blocked by the projection has no echo, just forming a shadow.

Compared with large targets such as shipwrecks and plane crashes, torpedo-shaped targets can retain more complete features. And they are always less covered by sediment. The disadvantage is that the image is greatly affected by the Marine environment, reverberation and noise. So the shape of the target is irregular and the edge is fuzzy. As a result, the formed boundary and texture features are not accurate. At the same time, due to the small size, the texture features in the target body are very fuzzy, so the detection algorithm can only be designed from the contour, showed in figure 2. This kind of image is generally low resolution. The background characteristics are similar to the desert, so the image must be smoothed firstly.

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![Figure 1. Algorithm flow chart](image1)

![Figure 2. Original SAR image](image2)
similar colors are grouped together, the edge information between different blocks will be clearly presented. On this basis, the edge detection of such targets can be carried out.

Meanshift filtering principle

$n$ sample points are given from $D$-dimensional space $R^d$, $i = 1 \cdots n$, select any point $x$ in space, the basic Meanshift vector form is:

$$M_h = \frac{1}{K} \sum_{x_i \in S_h} (x_i - x)$$

(1)

$S_h$ is a high dimensional sphere region with radius $h$, a set of $y$ points satisfying the following relations:

$$S_h(x) = \{ y : (y-x_i)^T(y-x_i) < h^2 \}$$

(2)

Where, $k$ means that in $n$ sample points $x_i$, there are $k$ points falling into area $S_h$.

Generally speaking, pick a random point $x_i$, there are $k$ points falling into area $S_h$.

Then, center on the end of the Meanshift vector to make a high-dimensional ball. Repeat the above steps and another Meanshift vector will be got. Finally, Meanshift algorithm could converge to the place with the greatest probability density, and it is the most heavily populated areas.

By adding the basic Meanshift vector into the kernel function, the Meanshift algorithm is deformed as:

$$\hat{f}_{h,k}(x) = \frac{c_{k,d}}{nh^d} \sum_{i=1}^{n} \left( \frac{x-x_i}{h} \right)^2$$

(3)

$K(x)$ is the kernel function, $h$ is the radius, $C_{k,d} / nh^d$ is the unit density. In order to make the formula $f$ maximum, the easiest way is to derive the above formula. The Meanshift algorithm is actually deriving the above formula.

$$\nabla \hat{f}_{h,k}(x) = \frac{2c_{k,d}}{nh^{d+2}} \sum_{i=1}^{n} (x-x_i) k' \left( \frac{x-x_i}{h} \right)$$

(4)

make:

$$g(x) = -K'(x)$$

$K(x)$ is the shadow kernel of $G(x)$, which is actually the negative direction of derivation. Then the above formula becomes:

$$\hat{f}_{h,k}(x) = \frac{2c_{k,d}}{nh^{d+2}} \sum_{i=1}^{n} (x_i - x) g \left( \frac{x-x_i}{h} \right)$$

(5)
\[ f_{h,G}^\wedge (x) = \frac{c_{g,d}}{n h^d} \sum_{i=1}^{n} g \left( \frac{\|x - x_i\|_h}{h} \right) \]  

(6)

The second term is the expression of a Meanshift vector:

\[ m_{h,G} (x) = \frac{\sum_{i=1}^{n} x_i g \left( \frac{\|x - x_i\|_h}{h} \right)}{\sum_{i=1}^{n} g \left( \frac{\|x - x_i\|_h}{h} \right)} \]  

(7)

Then formula (4) can be expressed as

\[ \nabla f_{h,K} (x) \equiv f_{h,G}^\wedge (x) \frac{2 c_{k,d}}{h^2 c_{g,d}} m_{h,G} (x) \]  

(8)

To make \( \nabla f_{h,K} (x) = 0 \), if and only if \( m_{h,G} (x) = 0 \), a new center coordinate can be obtained:

\[ x = \frac{\sum_{i=1}^{n} x_i g \left( \frac{\|x - x_i\|_h}{h} \right)}{\sum_{i=1}^{n} g \left( \frac{\|x - x_i\|_h}{h} \right)} \]  

(9)

3. Algorithm Illustration

Step 1, convert RGB color mode to Luv mode. L represents brightness, u and v represent hues. In this color mode, the influence of L brightness on segmentation can be reduced to a limited extent.

Step 2, a seed points were randomly selected in Luv mode, and the color difference threshold and spatial neighborhood size were set. In a D-dimensional space (a 5-dimensional space made up of \( x, y \) and Luv), pick a random point and make a higher-dimensional sphere with this point as the circle center and \( h \) as the radius.

All the points and the center of the circle that fall into the ball will produce vectors. Then add the vectors (the Gaussian kernel of space and color difference as the weight of the vector) and the result is the Meanshift vector.

When the Meanshift vector's modulus length is less than the threshold (the similar degree when the value is convergent, the bigger the value, the more fuzzy the image), the convergence is indicated. And then, all the point color values on the mean movement trajectory are assigned to the color value of the convergence point. All points of the whole image will converge to a certain peak point (the point at the end of the previous algorithm iteration).

Step 3, merge all the point groups formed in the previous step. The color values of the point group with similar color values and adjacent convergence points, are all assigned to the color mean value of the convergence points, so as to complete the filtering. The result will be a rather fuzzy, smooth image, shown in figure 3.
Step 4, Ostu binarization. The gray value of the whole picture is calculated by histogram statistics. Then, the gray threshold value is found, in which the difference between the gray mean of the previous part that is smaller than the threshold, and the gray mean of the latter part that is greater than the threshold, is the largest.

All values above the threshold are assigned to white, and all values below the threshold are assigned to black. Of course, The target is white.

Step 5, Region growth. By Region growth, the larger white area is cleared, for the large area doesn't conform to the target characteristics. The result is shown in figure 4.

4. Conclusions

The proposed algorithm is stable, fast and reliable for the detection of underwater stationary torpedo-shaped artificial targets in the real SAS image data. But in the use of reliability and robustness, it found that validation algorithm, several threshold parameters of the proposed algorithm are greatly influenced by the sonar image brightness. If the light area that similar to the image brightness exist in the image, the detection false alarm rate would increase. In addition, since the binarization threshold of Ostu algorithm is obtained through the statistics of histogram information, it has better stability and processing effect for images from similar data sources. However, if the images from other data sources differ greatly from such images, the threshold obtained from each recalculation could has a great impact on the processing results.

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