COA 2016 中国海洋声学研讨会
IEEE/OES China Ocean Acoustics Symposium
Harbin, China | January 9-11, 2016

The Application of NDT Algorithm in Sonar Image Processing

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***Abstract*—Image matching technology is an important part of image processing technology. In this paper, the normal distributions transform (NDT) image matching algorithm and its application in the sonar image processing is studied. The NDT algorithm is based on a probability model. It calculates the co-ordinate of the image of the target point instead of the grey value, and this speeds up the sonar image matching process. Previously, before image matching was available, per-processing of the sonar image was necessary. The research of pre-processing of sonar imaging concerns noise reduction and image segmentation of the sonar image. Several classical methods of sonar image noise reduction are studied. The advantages and disadvantages of each method are analyzed. Based on a kind of DSP chip, the NDT image matching algorithm is achieved.**

Keywords—image matching; DSP; sonar image processing; normal distributions transform

I. INTRODUCTION

Sonar image processing is of great importance in underwater signal processing, and has great value in economic and military terms. In recent years, image matching technology has been widely applied in fields such as navigation, medical image processing, astronomy, target tracking, and also fingerprint identification, but, it is rarely applied in sonar image processing. The normal distributions transform (NDT) algorithm is based on a probability model which can speed up the sonar image-matching process. Based on the image of divers, several pre-processing algorithms are studied. The advantages and disadvantages of each method are analyzed. The method which meets the requirements of real-time is selected. Then the NDT algorithm is used for the sonar image matching processing, and archived on a DSP chip.

II. PRINCIPLE OF NDT

The NDT algorithm was developed by Biber P, Strasser W [1] and has been widely used in SLAM. But it is rarely applied in underwater acoustics. The main idea of NDT is transforming the points of a 2D image into a collection of pixels - which can be expressed as the probability distribution of a piecewise continuous differentiable function. According to the probability distribution of two images, we can match them quickly.

The NDT models the distribution of all reconstructed 2D-points of one image by a collection of local normal distributions, in the following manner :

1) Collect all 2D-points contained in a small cell.

2) Calculate the mean q and the covariance matrix Σ.

$$q = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

$$\Sigma = \frac{1}{n}\sum_{i=1}^{n}(x_i - q)(x_i - q)^T \tag{2}$$

The probability of the 2D-points in this cell is modeled by the normal distribution.

$$p(x) \sim \exp\left(-\frac{(x-q)^T \Sigma^{-1}(x-q)}{2}\right) \tag{3}$$

We call this process as building a NDT of an image. Given two images, the steps of the NDT algorithm are as follows:

1) Build the NDT of the first image.

2) Initialize the estimate for the parameters.

3) For each sample of the second image. According to the parameters, map the 2D-points into the co-ordinate frame of the first image.

4) Determine the corresponding normal distributions for each point.

5) Calculate the score which can evaluate the distribution for each point, summing the result.

6) Calculate a new parameter estimate by trying to optimize the score.

7) Go to 3 until a convergence criterion is met.

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The score is defined as:

$$score(p) = \sum_{i}^{n} \exp\left(-\frac{-(x_i' - q_i)^T \Sigma_i^{-1} (x_i' - q_i)}{2}\right) \quad (4)$$

p is the vector of the parameters to estimate. x_i' is the point x_i mapped into the coordinate frame of the first scan according to the parameters p. The NDT algorithm is used to search for the best vector p, which makes the score be a maximum.

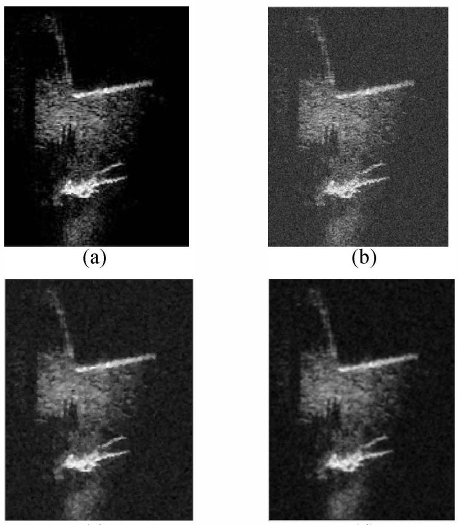
III. SIMULATION

For the existence of random noise in the ocean and the vessel noise, the sonar images we get are not the most suitable for matching. So, before the matching processing, pre-processing of the sonar image is necessary [2]. Several noise reduction methods are studied in this paper and applied to the sonar image, including: the mean method; the median method; the morphological smoothing method; and, the technology based on wavelet.

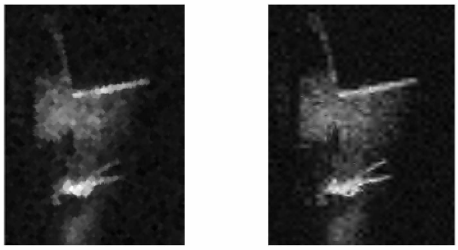
The NDT algorithm calculates the co-ordinates of the target pixels in the image, and has nothing to do with the grey value. So, the image segmentation is processed before the image matching in order to separate the target and the background. In this paper, several algorithms of image segmentation are analyzed and simulated, including the iteration method, the One-dimensional maximum entropy method, and the Otsu [3] method.

A. Simulation of Noise Reduction

The original sonar image is the picture of divers, adding Gaussian noise. The mean of the noise is 0, the standard deviation are 0.1, 0.2, 0.3 and 0.4. Using the noise reduction algorithms mentioned above and calculating the PSNR and the MSE, the two values of each method are compared. Fig. 1 is the simulation of different noise reduction algorithms; the standard deviation of the noise is 0.4. Table I is the time which each method costs, and table II is the value of PSNR and MSE of each method.



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



(e) (f)

Fig.1. (a) Original image; (b) Noise image; (c) Median method; (d) Mean method; (e) Morphological smoothing method; (f) Technology based on wavelet.

TABLE I. TIME OF EACH NOISE REDUCTION METHOD

Method	Time (s)
median method	0.045952
mean method	0.002032
technology based on wavelet	0.368323
morphological smoothing method	0.189010

TABLE II. TIME OF EACH NOISE REDUCTION METHOD

Method	Parameter	
	PSNR	*MSE*
mean method	23.7308	0.0041
median method	23.8318	0.0040
technology based on wavelet	23.0682	0.0048
morphological smoothing method	20.1384	0.0096

From the table we can see that the time of the mean method and median method is shorter than in the case of the other two algorithms. According to the PSNR, the mean method and median method are better. The MSE of the mean method and median method is smaller than the morphological smoothing method and the technology based on wavelet. From Fig.1, we can see that the results of the noise reduction of the morphological smoothing method and of the technology based on wavelet are better than the other two. But at the same time, the image is blurred. Compared with the mean method, the median method can preserve some edge information whilst de-noising the image. Compared with the morphological smoothing method and the technology based on wavelet, the median method is simple and convenient, and the calculation time is short, which is suitable for practical application. Through the above analysis, the median method is used as the image pre-processing algorithm in this paper.

B. Simulation of Image Segmentation

The image segmentation simulation of different algorithms is presented in Fig.2. TABLE III records the threshold and time of each method.

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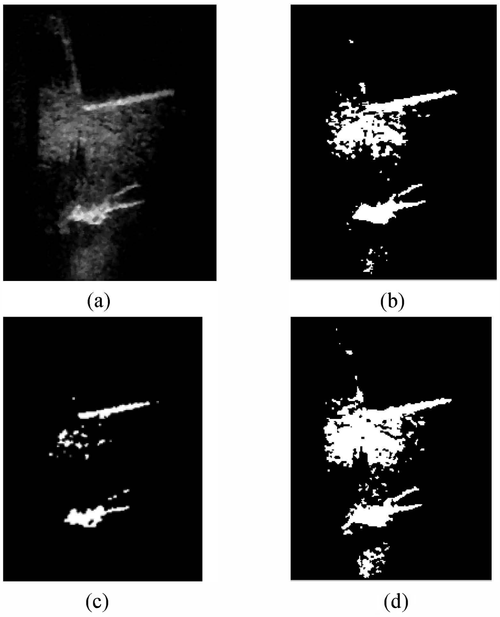


Fig.2. (a) Original image; (b) Iteration method; (c) One-dimensional maximum entropy method; (d) Otsu method.

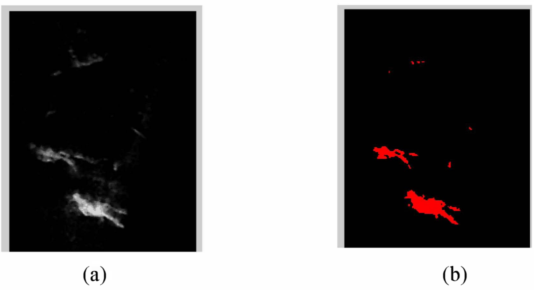
TABLE III. THRESHOLD AND TIME OF IMAGE SEGMENTATION ALGORITHM

Method	Parameter	
	threshold	*time (s)*
iteration method	61	0.037710
One-dimensional maximum entropy method	89	0.634523
Otsu method	43	0.104841

As we can see from the table, the operation time of the Otsu method and the iteration method is shorter than the One-dimensional maximum entropy method; and, the threshold of the One-dimensional maximum entropy method is the largest. From the Fig.2, we can see that the edge of the diver is classified as the background, and there is over-segmentation. The results of matching are affected by the selection of image segmentation algorithm. By considering the effect of segmentation and the real-time requirement, the Otsu method is selected.

C. Simulation of The NDT Algorithm

The simulation of the NDT image matching processing is presented in Fig.3.



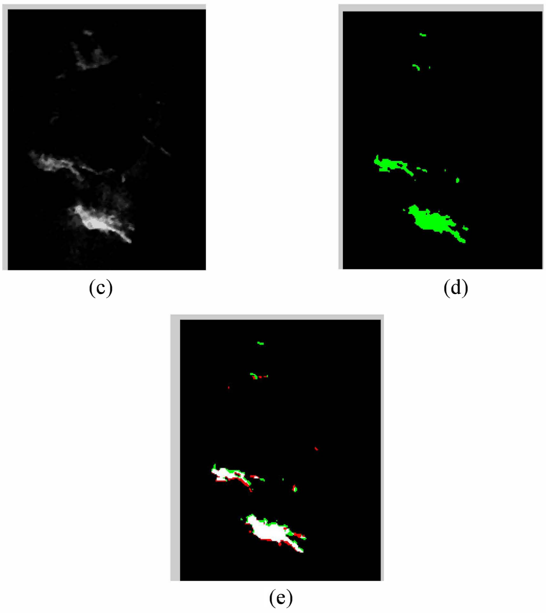


Fig.3. (a) First image; (b) Image segmentation results of the first image; (c) Second image; (d) Image segmentation results of the second image; (e) Results of the NDT image matching processing.

From Fig.3, picture b and picture d are the result of image segmentation processing; and the targets are presented with different colors. Picture e shows the results of image matching - the white area of the target is the matching part. The parts containing other colours is not overlapping, and its area is very small - the reason is the probability ratio of this area is not large enough, and the coordinates in these two picture are different.

IV. ARCHIVE ON DSP CHIP

All of the above algorithms are achieved on DSP chip TMS320C6713 [4] from TI Inc. The software is CCS3.3. CCS can not read the general format image files, so we use MATLAB to transform the image file to the ".dat" file. Then we download the ".dat" file to the SDRAM.

The NDT image matching program is written in C language. The whole image matching process is realized, including noise reduction, image segmentation and image matching.Fig.4 is the flow chart of program. Fig.5 is the hardware. Fig.6 to Fig.8 is the results of the image processing on DSP.

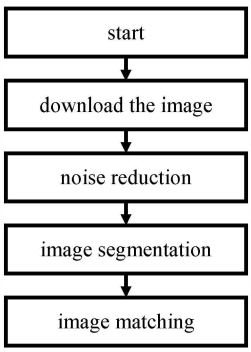


Fig.4. Flow chart.

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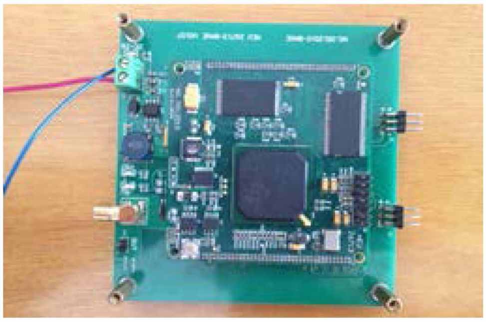

Fig.5. Hardware.

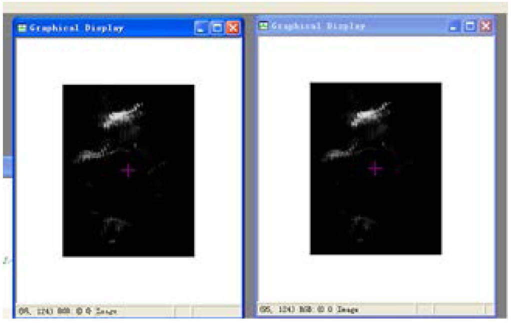

Fig.6. Noise reduction on DSP.

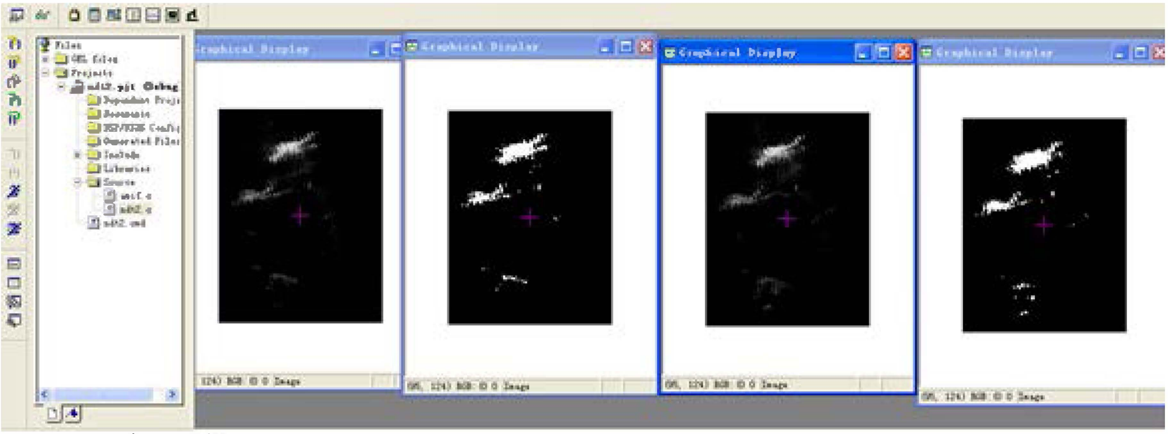

Fig.7. Image segmentation on DSP.

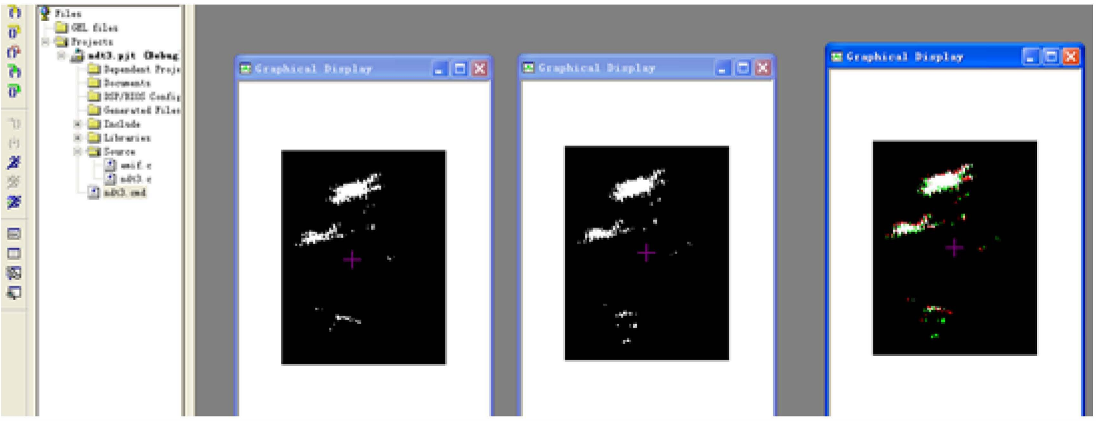

Fig.8. NDT image matching algorithm on DSP.

V. CONCLUSION

In this paper, the normal distribution transformation algorithm is studied and used in the sonar image-matching process. Before image matching, several methods of noise reduction and image segmentation are studied. The median method and the Otsu method are chosen as the most appropriate pre-processing algorithm to go through the simulation results analysis and comparison. According to the results of noise reduction and image segmentation, the sonar image matches with the NDT algorithm. Finally, real-time matching of sonar image is archived on a DSP chip .

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