Study on the Fusion of MBS Image and SSS Image

Hongmei Zhang
Automation Department
Wuhan University
Wuhan, China, 430072

Jianhu Zhao
School of Geodesy and Geomatics
Wuhan University
Wuhan, China, 430079

Kun Yang
Tianjin Research Institute
for Water Transport Engineering
Tianjin, China, 300456

***Abstract*-Both the images of MBS and SSS can reflect the seabed relief, considering their respective characteristics, the fusion of the two images is studied in this paper. Image preprocessing technique, image registration and matching method, multi-resolution wavelet analysis and transform algorithm, image fusion as well as the evaluation are discussed in the research. Experiment results show that the fusion enriches the information of original images and enhances the seabed expression of sonar image.**

I. Introduction

Multibeam bathymetric system (MBS) can provide sounding data and backscatter strength. The backscatter strength can be transformed to gray level. Thus, MBS can acquire the seabed image which is used for reflecting the features of seabed relief. Limited to MBS operation model, the resolution of MBS image is lower relative to side scan sonar (SSS) image. SSS is mainly used for seabed relief investigation, which has higher image resolution and quality. Both the images of MBS and SSS reflect the same seabed relief characteristics, thus it becomes necessary to implement the fusion to MBS image and SSS image so as to enhance image quality, enrich the information of seabed relief image and accurately present the seabed relief features [1]. Pixel-level data fusion is adopted in the work. The fusion keeps the original observation information to maximum extent and provides more subtle information compared with the other image fusion methods.

In order to fulfill the fusion, image preprocessing technique, image registration and matching method, multi-resolution wavelet analysis and transform algorithm, image fusion as well as the evaluation of image fusion are studied. In the following, the fusion method will be depicted in detail.

II. Image Preprocessing

Influenced by many factors, both SSS image and MBS image need to be preprocessed. The process concerns some distortion corrections such as geometric distortion correction, gray distortion correction and so on, and the basic image process such as image smoothing, image enhancement as well as edge detection and segmentation and so on. Both image distortion process and image smoothing improve the image quality. The other image processes ensure the extraction of seabed characteristic objects.

The image distortion process can be done by some ready-made software, while the image smoothing processing can be implemented by wavelet filter or median filter[2][3].

Known research has proved that both median filter and wavelet filter suit for the filtering of MBS image and SSS image. Considering the convenience in actual image processing, median filter is adopted in this paper. Fig. 1 shows the filter processing by median filter.

In order to get the relationship between MBS image and SSS image, both image enhancement and sharpening are necessary so as to highlight the characteristic targets in the two images. In the image enhancement, histogram equalization is adopted, while Sobel differential operator is used for the image sharpening. Fig. 2 shows the MBS image and SSS image after image enhancement and sharpening processing.

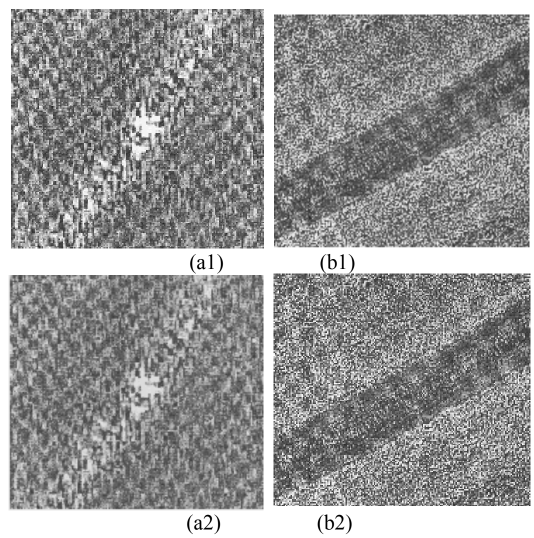

Figure 1. The filtering for MBS image and SSS image based on median filter. (a1) and (b1) are raw MBS image and SSS image, (a2) and (b2) are corresponding filtered images.

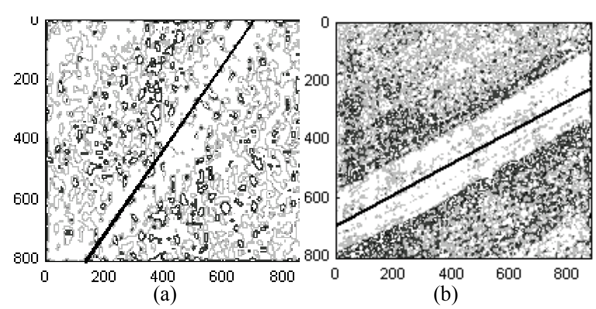

Figure 2. MBS image (a) and SSS image (b) after image enhancement and sharpening processing.

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After above processing, the image registration and match of MBS image and SSS image can be implemented by following.

III. Registration and Match of SSS Image and MBS Image

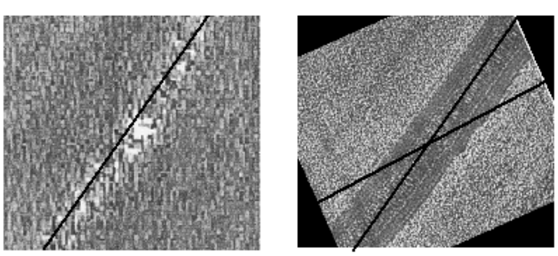
In order to fulfill the fusion of MBS image and SSS image in the same coordinate frame (such as geographic reference frame), image registration is a necessary work in the fusion. In SSS observation, ultra short baseline locating system (USBLS) needs to be adopted so as to provide accurate positioning information for SSS towfish. However, in many marine investigations, USBLS is not used for SSS observation. In MBS observation, MBS transducer is installed in the surveying vessel, while GPS is also fixed on the vessel for providing accurate position to MBS transducer. Thus, in theory, both MBS image and SSS image can be registered in geographic reference frame (GRF) if USBLS is adopted in SSS observation. For normal SSS observation, in order to weaken the influence of SSS towfish attitude and positioning furthermore, the velocity of surveying vessel is limited within 3 knots in SSS measurement. For all that, the traditional image matching method based on characteristic point pairs is also used so as to weaken the influences of positioning error as well as other factors. The transformation parameters such as coordinate translation and rotation angle of the two images are determined by the match of feature point pairs [4][5][6].

In Fig. 2, in virtue of the results after image enhancement and sharpening, a characteristic line is found in MBS image. The corresponding characteristic line is also found in SSS image. According to the coordinates of the two lines in corresponding images, the transformation relationship, namely translation and rotation angle, can be calculated.

According to the relationship between the two characteristic lines, the SSS image is transformed (see Fig. 3). The SSS image fulfills the image match with MBS image. The matched MBS image and SSS image can be used for image information fusion in following work.

IV. Multi-resolution Wavelet Transform

Multi-resolution wavelet analysis method provides different-resolution information with different scales by decomposing the original image [1]. The decomposition is an iterative process, which is expressed as (1) [7][8][9].



(a) (b)

Figure 3. The image match between MBS image and SSS image transformed. (a) is the MBS image smoothed and (b) is the SSS image smoothed and transformed

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\begin{aligned}
s_{m,n}^{M+1} &= f(m,n) \\
s_{m,n}^{M} &= \sum_{i,k} h(i-2m)h(k-2n)s_{i,k}^{M+1} \\
\alpha_{m,n}^{M} &= \sum_{i,k} h(i-2m)g(k-2n)s_{i,k}^{M+1} \\
\beta_{m,n}^{M} &= \sum_{i,k} g(i-2m)h(k-2n)s_{i,k}^{M+1} \\
\gamma_{m,n}^{M} &= \sum_{i,k} g(i-2m)g(k-2n)s_{i,k}^{M+1}
\end{aligned} \tag{1}
$$

Where, $f(m,n)$ is the discrete sampling of original image. $s^{M}_{m,n}$ is the scale coefficients in scale M, which is the low frequency part at both m direction and n direction. $\alpha^{M}_{m,n}$, $\beta^{M}_{m,n}$ and $\gamma^{M}_{m,n}$ are wavelet coefficients in scale M, in which, $\alpha^{M}_{m,n}$ is the low frequency part at m direction and high frequency part at n direction, $\beta^{M}_{m,n}$ is the high frequency part at m direction and the low frequency part at n direction and $\gamma^{M}_{m,n}$ is the high frequency part at m direction and the high frequency part at n direction.

Usually $f(m,n)$ is considered as $s^{M+1}_{m,n}$. Equation (1) shows that the scale coefficient $s^{M+1}_{m,n}$ can be decomposed into four parts, $\alpha^{M}_{m,n}$, $\beta^{M}_{m,n}$, $\gamma^{M}_{m,n}$ and $s^{M}_{m,n}$, and $s^{M}_{m,n}$ can be decomposed into four part further, which are in the lower frequency scale and have lower resolution. The original image can be decomposed into multiple parts with different frequency and resolution by repeating the process[10].

Furthermore, If the four part, $\alpha^{M}_{m,n}$, $\beta^{M}_{m,n}$, $\gamma^{M}_{m,n}$ and $s^{M}_{m,n}$ of an image, can be acquired, the image can be reconstructed by multi-resolution wavelet transform.

Above theory provides a way for the fusion of the MBS image and SSS image.

V. Fusion of SSS Image and MBS Image

In virtue of image registration and image match, the MBS image and SSS image is expressed in the same coordinate frame such as GRF.

Above procedures of image decomposition and image reconstruction show that we can implement wavelet decomposition for two different-resolution sonar images, and reconstruct a new image with $s^{M}_{m,n}$ from the low-resolution image and $\alpha^{M}_{m,n}$, $\beta^{M}_{m,n}$, $\gamma^{M}_{m,n}$ from the high-resolution image.

Based on multi-resolution wavelet transform, SSS image and MBS image can be decomposed into different frequency-band information, and used for the reconstruction of a new image. Before the work, it is necessary to choose an appropriate wavelet basis. The previous research shows that dB3 wavelet basis is optimum for implementing the decomposition and reconstruction of the sonar image. The resolution of SSS image is higher, while that of MBS image is lower. Thus the low-frequency part $s^{M}_{m,n}$ should be from MBS image, and other frequency-band parts ($\alpha^{M}_{m,n}$, $\beta^{M}_{m,n}$, $\gamma^{M}_{m,n}$) should be from SSS image. Then, a new image can be constructed by (2).

$$I = s_{m,n}^{MBS} + \alpha_{m,n}^{SSS} + \beta_{m,n}^{SSS} + \gamma_{m,n}^{SSS} \tag{2}$$

VI. EVALUATION OF IMAGE FUSION

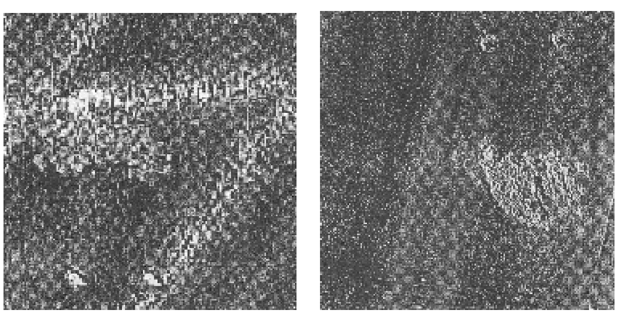
The image fusion effect is evaluated by these parameters, such as image entropy, image average gray, image average gradient and information entropy[11]. These standards reflect the information level, image definition, image contrast as well as texture characteristic variation of the image. By comparing above information of the two original images and those of the reconstructed one, the effect of the image fusion based on the method presented in this paper can be evaluated.

VII. EXPERIMENT AND ANALYSIS

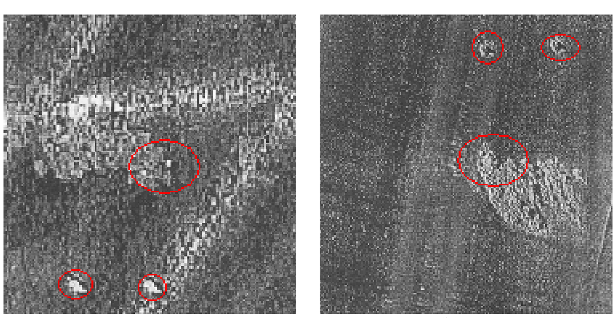
The MBS image and SSS image in an experimental water area were acquired by multibeam bathymetric system and side scan sonar system, and shown in Fig.4.

From Fig. 4, it is not difficult to find that the resolution of MBS image is lower than that of SSS image. Besides, some noises exist in the two images. In order to ensure image quality for image fusion, the image smoothing based on median filter is adopted for the two images. The filtered images are shown in Fig. 5.

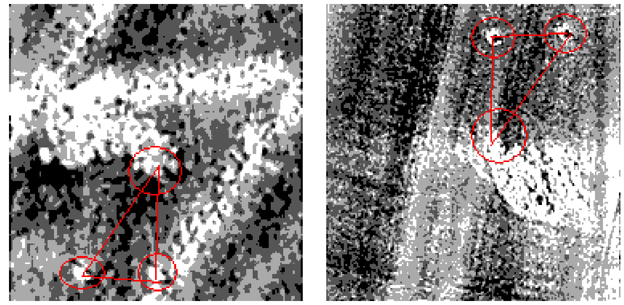
After filtering, the image quality is improved (see Fig. 5). 3 characteristic target pairs are found in the two images, and are marked with circles in Fig. 5. In order to enhance and sharpen these characteristic targets, both image enhancing and image sharpening are used for the two images. After this step, these characteristic targets are enhanced in the two images further (see Fig. 6).



(a) (b)
Figure 4. Raw MBS image (a) and SSS image (b)



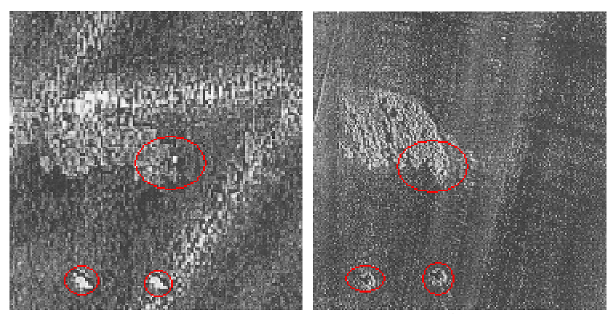
(a) (b)
Figure 5. MBS image (a) and SSS image (b) after median filter



(a) (b)
Figure 6. Enhanced and sharpened MBS image (a) and SSS image (b)

According to the coordinates of these characteristic targets in their corresponding images, the relationship of the two images, namely translation and rotation angle, is determined. In virtue of the transformation relationship, the filtered SSS image shown in Fig. 5 is transformed and formed a new image shown in Fig. 7 (b).

The MBS image and SSS image shown in Fig. 7 provide the original images for the fusion. The fusion adopts wavelet transform. Actually, for the image decomposition of each of sonar images, the four parts of the image, such as low-low frequency part, low-high frequency part, high-low frequency part and high-high frequency part can be extracted from the original image. The new image is reconstructed with the low-low frequency part from MBS image and the low-high frequency part, the high-low frequency part and the high-high frequency part from SSS image. Wavelet reconstruction takes the work. The reconstructed image is shown in Fig. 8.



(a) (b)
Figure 7. Matched MBS image (a) and SSS image (b)

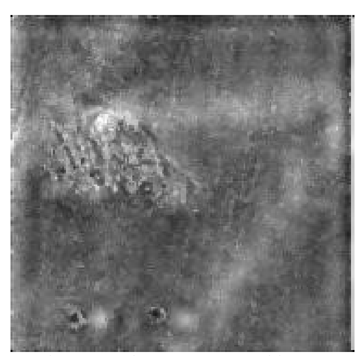


Figure 8. The reconstructed image

Comparing the reconstructed image and the two original images (See Fig.7 and Fig. 8), it is not difficult to find that the new image synthesizes the information of the two original images. Although the smooth of the new image is lower than that of the SSS image, but it is better than that of MBS. In order to quantitatively evaluate the performance of the image fusion, the evaluation parameters, such as image entropy, image gray average, image average gradient and information entropy, are calculated with the MBS image, the SSS image and the new image. These parameters are shown in Table I. Comparing these parameters, the reconstructed image richens the information of the two original images, increases the image entropy. Besides, the new image sharpens characteristic terrain targets and increases the average gray as well as average gradient. Moreover, image quality of the two original images are improved which is proved by decreased standard deviation.

TABLE I
EVALUATION PARAMETERS OF IMAGE FUSION

Image	MBS image	SSS image	The fusion image
image entropy	6.74	6.36	7.80
gray average	112.84	102.61	108.87
Standard Deviation	16.38	13.15	10.60
average gradient	0.22	0.21	0.07
information entropy	6.81	6.21	7.82

VIII. CONCLUSION AND SUGGESTIONS

Above research provides a way for the fusion of MBS image and SSS image. The experiment shows that the fusion can enrich the information of original image and enhance the seabed expression of sonar image. The work is a primary research in this paper. An ideal fusion result depends on higher original image quality and accurate image match between MBS image and SSS image. Besides, image pre-processing work is also very important in the research, which can ensure the quality of the image fusion.

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