DENSE MATCHING FOR THE DERIVATION OF SHALLOW WATER BATHYMETRY USING SATELLITE STEREOPAIRS

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ABSTRACT: This paper proposes a method using satellite stereopairs to reconstruct the bathymetry. The proposed method comprises three major steps: (1) image matching, (2) elevation calculation, and (3) refraction correction. Semi-global matching (SGM) is employed in the first step. Two matching cost assessments, namely, Normalized Cross Correlation (NCC) and Mutual Information (MI) are compared in this study. The matching starts from an initial bathymetry model. We calculate the disparity by SGM for each pixel pair. Then the elevation calculation is employed for 3D positioning via the disparity. The correction for refraction at the air/water interface is needed. Thus, we revise the bathymetry derived from elevation calculation through the incidence angles of satellite images at the final step. Experimental results show that the proposed method could yield the accuracy around 0.7 m for the reconstruction of shallow water bathymetry when WorldView-2 satellite image pairs were tested. The results also indicate that the MI performs better than NCC.

1. INTRODUCTION

To acquire bathymetric information, echo sounding and airborne bathymetry Lidar have been used for years. The first one achieves high quality results, while the platform has to be carried on the water with enough depth (Kao et al., 2009). The second approach is effective for shallow water areas. Nevertheless, it is subject to high cost. Satellite images, on the other hand, open another door for the derivation of bathymetry. One may use spectral characteristics of the image to retrieve water depth (Lyzenga, 1978). In general, the methods retrieve bathymetry with sufficient training data about water bottom reflectance, water properties, and so on (Kao et al., 2009). Working on the photogrammetric way, image matching is a practical method for the generation of digital elevation models. Through the image matching, the corresponding 3D coordinates can be determined by those conjugate image points and orientation parameters. The major difference between bathymetry and land surface is the light refraction effects. The refraction correction is, thus, made in this study.

Semi-global matching (SGM) (Hirschmüller, 2005) is a practical way for dense image matching, because both local and global image information are considered through pathwise aggregation to determine the conjugate points. Many researches have proven that it would be a robust matching algorithm (Gehrke et al., 2010; Haala, 2013).We, thus, employ SGM to reconstruct the bathymetry with satellite stereopairs. Two matching cost assessments, namely, Normalized Cross Correlation (NCC) and Mutual Information (MI) are compared in this study.

2. METHODOLOGY

The proposed method comprises three major steps: (1) image matching, (2) elevation calculation, and (3) refraction correction. SGM is employed in the first step. The matching starts from an initial bathymetry model. We calculate the disparity by SGM for each pixel pair. Then the elevation calculation is employed for 3D positioning via the disparity. The correction for refraction at the air/water interface is needed. Thus, we revise the bathymetry through the incidence angles of satellite images at the final step.

2.1 Image Matching

Starting from an initial bathymetry model, we back project each candidate to stereopairs. Notice that the initial model may be with a constant elevation when no other bathymetry information is available. One image is regarded as the master image. The target window is fixed at the back projection position. The search window on the slave image is moved along epipolar direction. SGM is employed to determine the conjugate points. The method contains two major steps: matching cost calculation and aggregation. The pervious step is to assess the image similarity locally for all candidate conjugates. Then, the pathwise aggregation is employed to minimize the cost along 1D paths. Two matching indices for matching cost calculation, namely, NCC and MI are compared in this study.

2.1.1 Normalized Cross Correlation: Considering that the brightness of the image varies due to lighting and exposure conditions, NCC evaluate the similarity via calculating the cross correlation with normalization between images (Lewis, 1995). The value of NCC is between -1 and 1.

2.1.2 Mutual Information: MI is a structural measurement of the mutual dependence between images by computing the entropy. The domain of MI for image matching depends on probability of grey value between matching windows. To compare MI with NCC, the normalized mutual information (NMI) (Pluim, et al., 2003) is employed in this paper. The value of NMI is between 0 and 1.

2.2 Elevation Calculation

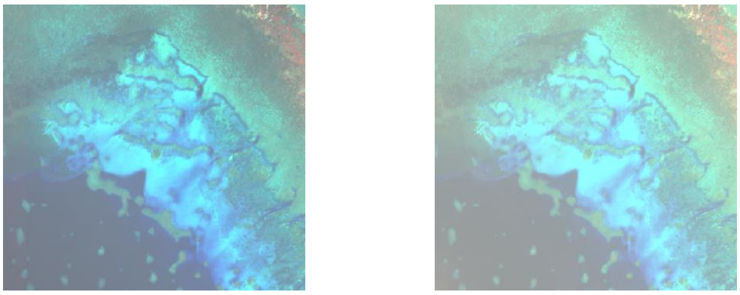
After image matching, the disparities for all candidates are obtained. The value of disparity is used to derive the elevation (Chen and Rau, 1993; Amitabh et al., 2005). In this study, the image coordinates with corresponding disparities and the initial bathymetry are used for 3D positioning.

2.3 Refraction Correction

By the nature of light refraction, the resulting three-dimensional coordinates of water depth will be shallower than it should be. Westaway et al. (2001) derived the correction formula for refraction with Snell's law. Based on the formula, we compute the refraction correction with two incidence angles of the stereopairs.

3. EXPERIMENTS

The test site locates in Dongsha of South China Sea. The test images are WorldView-2 satellite stereopais, as shown in Figure 1. The information about test images are shown in Table 1. The reference Bathymetry with 5 m spatial resolution is reconstructed by airborne bathymetry Lidar point clouds. The area is 1200 square meters; the range of bathymetry is about -1 m to -7 m. Figure 2 shows the reference bathymetry.



(a) Master Image (b) Slave Image

Figure 1. The Test Images

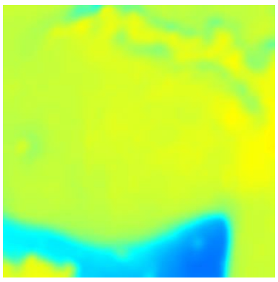


Figure 2. Reference Bathymetry

Table 1. Related information of test images

Satellite	Date	GSD_Cross (m)	GSD_Along (m)	Azimuth (degree)	Elevation (degree)	Convergence Angle (degree)
WorldView-2	2016/3/8	0.49	0.48	111.9	76.2	34.36
WorldView-2	2016/3/8	0.56	0.67	171.9	54.7	

The initial Bathymetry with 0.5 m spatial resolution is reconstructed by few manual measured points and Kriging interpolation. The results are shown in Figure 3. Table 2 indicates the accuracy of reconstructed bathymetry. As depicted in Figure 3, the elevation of initial Bathymetry is higher than the reference in the center area. The average error and root mean square error (RMSE) of initial Bathymetry are about 1.3m and 1.8 m, respectively. After the proposed treatment, both MI and NCC methods improved the quality, noticeably in the center area with higher elevation as in the initial bathymetry.

It is observed that the matched points from MI are more stable than the NCC's results, especially in the deeper area. There are also obvious incorrect region in shallow water area in the NCC's results. The accuracies for MI and NCC are about 0.7 m and 0.9 m, respectively. The depth of reconstructed bathymetry is discontinuous in some places due to blunder and interpolation. Thus, it is subject to further processing for better surface continuity.

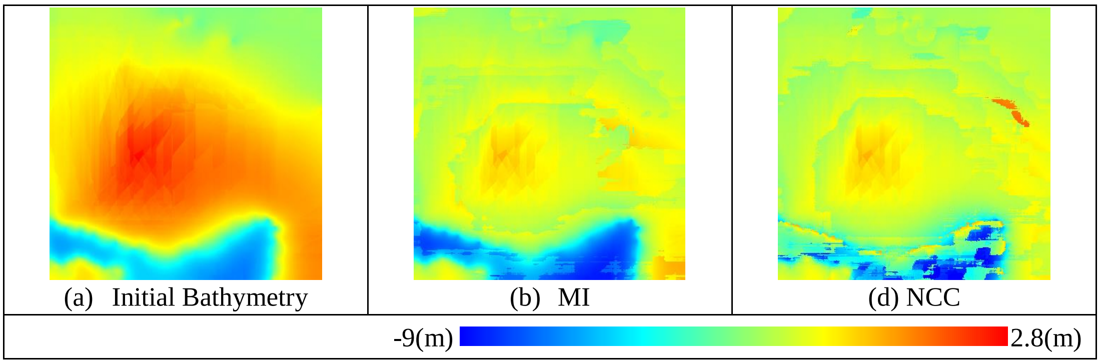


Figure 3. The Reconstructed Bathymetry

Table 2. Accuracy of Bathymetry

	Initial Bathymetry	MI	NCC
RMSE (m)	1.81	0.67	0.89
Average (m)	1.29	-0.01	0.10

4. CONCLUSIONS

In this investigation, we have reconstructed the bathymetry using WorldView-2 satellite stereopais with some 0.5 m spatial resolution. Two matching cost assessments, NCC and MI are compared. The experimental results indicate that the MI may better than NCC. And the RMSE of MI and NCC are 0.69 m and 0.89 m, respectively. However, there are some incorrect matched points in both results. The improvement of the matching reliability and surface continuity is subject to further investigation.

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