3^D SEAFLOOR RECONSTRUCTION USING DATA FROM SIDE SCAN AND SYNTHETIC APERTURE SONAR

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Side scan and synthetic aperture sonars are widely used imaging systems in the underwater environment. They are relatively cheap and easy to deploy, in comparison with more powerful sensors, like multibeam echosounders. Although side scan and synthetic aperture sonars does not provide seafloor bathymetry directly, their records are finally related to seafloor images. Moreover, the analysis of such images performed by human eye allows creating semi-spatial impressions of seafloor images obtained from side scan sonar echograms.

In the paper, some techniques for 3^D seafloor shape reconstruction from side scan and synthetic aperture sonars are presented. They are based on Shape From Shading (SFS) approach, which is one of classical problems in computer vision. The method for reconstruction of 3D seafloor relief using the information from both the currently processed and previous ping is presented. The advantage of the presented methods is their simplicity and the ability to produce the results within sequential, i.e. "one run" processing of side scan sonar image. Another algorithm relies on estimating the altitude gradient of the insonified surface from sonar data, combined with the use of dimension of shadow areas for estimation of the current elevation change. The presented results are promising and also show to some extent how the performance of the proposed algorithm might be improved in further investigation.

INTRODUCTION

3D acoustic imaging of the seafloor has become increasingly important for different underwater engineering activities such as pipeline tracking, wreck inspection, mine hunting and seafloor monitoring and characterization. At present, acoustic sensors offer the most reliable sight inside underwater environments for these purposes. They offer a longer range and wider angle coverage compared to video cameras or other sensors and map well the environment in turbid waters.

Side scan and synthetic aperture sonars are the most widely used imaging systems in underwater environment. They are relatively cheap and easy to deploy in comparison with more powerful sensors like multibeam sonars. However, they have some limitations, such as their inability to directly recover the seafloor depth or submerged object information. Lately, a lot of very attractive images of seafloor and wrecks have been obtained by modern multibeam sonars, what allows for their direct 3D visualization [1]. However, many 2D images acquired by side scan sonars exist, that could be transformed into 3D representation in an algorithmic way using echo intensity information, contained in grayscale images.

In sonar imaging systems, the knowledge on the phenomena of backscattering of acoustic energy by a target on the seafloor is used. The backscatter from the seafloor is generally considered to be composed of a combination of surface and volume scattering, i.e. roughness interface scattering and scattering from inhomogeneities within the sediment volume. It has been suggested by Jackson [2] that Lambert's Law provides a good fit to seabed backscattering since roughness and volume scattering mechanisms tend to mimic Lambert's Law. Consequently, he has compared Lambert's Law to his composite roughness backscattering model and the obtained results justify that Lambert's Law may be considered to provide a good approximation of seafloor backscattering.

Several techniques of 3D geometry reconstruction for seabed surface or submerged objects using side-scan sonar images has been reported [3]. Mainly, they use the techniques based on the problem inverse to image formation, namely Shape From Shading (SFS), which is one of classical problems in computer vision (see [4] for a collection of significant papers on SFS). In the construction of a seabed elevation map from side-scan images, the SFS technique relays on calculating the local slope of bottom relief, given the image pixel intensity, the assumed dependence of bottom surface backscattering coefficient on incident angle (what corresponds to reflectance map in classical SFS), and the estimated local incident angle value. The Lambert's Law is often used as a model of the angular dependence of the bottom scattering coefficient.

In this paper, the method for 3^D seafloor shape reconstruction from side scan and synthetic aperture sonar is presented. The method is based on the SFS approach. For estimation of a bottom depth at a given pixel of sonar image, it uses the information from both currently processed and previous ping and assumes that a local surface element spatial orientation has two degrees of freedom. The method consist of local altitude gradient estimation by SFS algorithm and the estimation of the elevation change using the dimension of acoustic shadow areas.

1. ALGORITHM FOR 3^D SEAFLOOR RECONSTRUCTION AND RESULTS

Previously [5], the procedure of seafloor 3^D shape reconstruction was developed and tested on side scan sonar data. The following assumptions were used:

1. straight line propagation path of acoustic wave in water column,
2. reflectivity model is known,
3. altitude H of the sonar transducer is known,
4. the normal to an insonified surface is perpendicular to y axis, e.g. to the track direction (it was applied as the simplest way of removing the problem of ambiguity in the relation

between reflectance and a surface element orientation, where the latter has two degrees of freedom in general),
5. the dimensions along vertical (z) axis of an object to be reconstructed are small in comparison with the sonar transducer altitude,
6. the intensity (grey level) of a pixel on sonar image is proportional to the acoustical intensity of backscattered echo.

As a results of further works two changes have been made [6]:
1. the assumption 4) was not applied, what allowed the local surface element orientation to have two degrees of freedom,
2. no shadow zone occurrence was assumed.

Sample seafloor image obtained from original side scan sonar survey is presented in Fig. 1. The reconstruction results are presented in. Fig. 2a. The magnified images of the selected part of reconstructed bottom surface are presented in Fig. 2b.

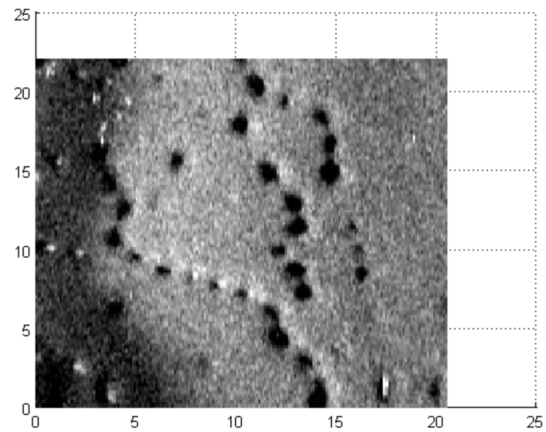

Fig.1. Sample seafloor image obtained from side scan sonar data

a) b)

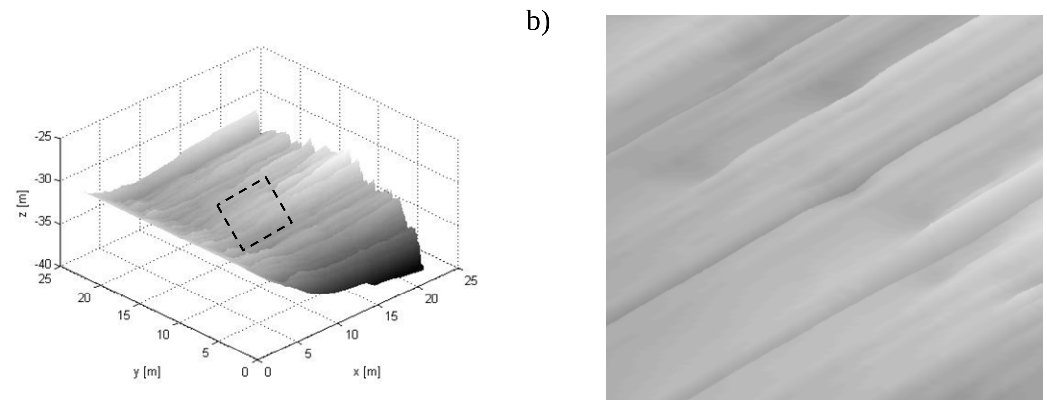

Fig.2. a) Bottom shape reconstruction results b) The enlargement of the selected parts of the surfaces

What may be clearly seen from the above figures, the results obtained from real data are to large extent not so good as in the case of artificially generated data. In addition, another modification of the seafloor reconstruction algorithm was proposed and preliminarily tested. To illustrate this modification, Fig. 3a presents the example of two adjacent vertical sections of the reconstructed bottom relief $z(x, y)$ from Fig. 2 parallel to x axis, corresponding to 2 consecutive sonar pings. It is visible that starting at some x value, nearly 4 meters in Fig. 3a, the altitude of the curves diverge, but:

- the local slopes of two presented profiles are generally consistent,
- besides divergence of curves, the difference between their z values remains nearly constant for majority of x co-ordinate values,
- several details of the seafloor topography, like a “hole” close to the right side of the picture, are represented quite similarly both in 1st (solid) and 2nd (dotted) curve.

It seems that when some “perturbation” of the seafloor shape is detected (which was not detected during processing the previous ping), like for instance, something similar to a hole in the left part of the 2nd curve – at the place of divergence, the algorithm is not able to recover to the proper altitude of the relatively flat seafloor area around the “perturbation”. It may be a consequence of some inconsistency between the assumed Lambertian scattering model and the reality.

As the additional justification of the above effect, the variability of the estimated local slope of $z(x, y)$ surface along x axis corresponding to 2 consecutive sonar transmissions (the same two as in Fig. 3a) are presented in Fig. 3b. Before plotting, the local slope was averaged for groups of 5 current, adjacent samples along x axis. It may be seen that for regions of “perturbations”, the averaged slope differs significantly for two consecutive curves in an image parallel to x axis, while is quite similar in other regions.

Taking the above phenomena into account, the following correction was proposed for the reconstruction algorithm: during processing the current ping, if the estimated local slope for the current seabed vertical section starts to be back similar to the slope of the previous profile (corresponding to the previous ping) after some interval of significant differences between those slopes (as in the place indicated by the arrow in Fig. 3b), then the z_{ij} value is set as equal to $z_{i-1\,j}$ value. Afterwards, the algorithm continues in a similar manner as previously. To distinguish when the slopes of two consecutive profiles are similar and when they are not, the current difference of these two slopes is being calculated and compared with some threshold value applied.

a) b)

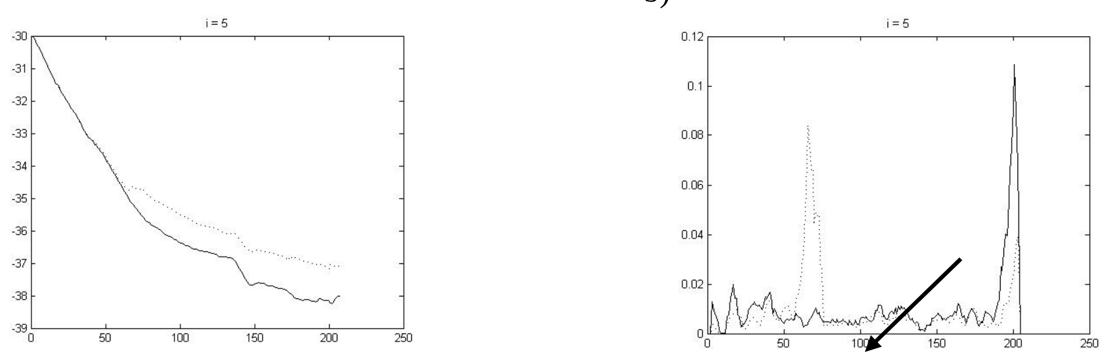

Fig.3. a) Example of two adjacent vertical sections of the reconstructed $z(x, y)$ from Fig. 2 along x axis, b) averaged local slope of $z(x, y)$ for these cross-sections

The results of application of the algorithm with this modification are presented in Fig. 4 and 5. The improvement with respect to the results presented in Fig. 2 is seen, as the inconsistency of adjacent lines and the resulting large surface undulations along y axis was removed to some extent. It is especially visible when comparing the cases of magnified reconstructed surface – Fig. 2b and Fig. 4b.

a) b)

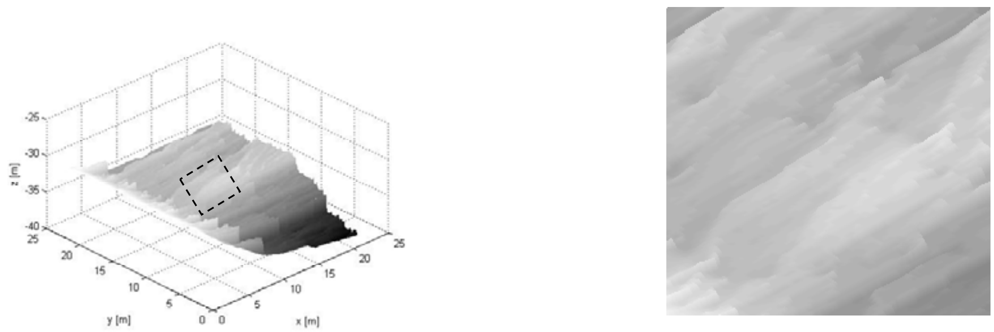

Fig.4. a) Results of application of the modified version of seafloor relief reconstruction algorithm, b) magnification of the selected part (the same as in Fig. 2) of reconstructed seabed surface from a)

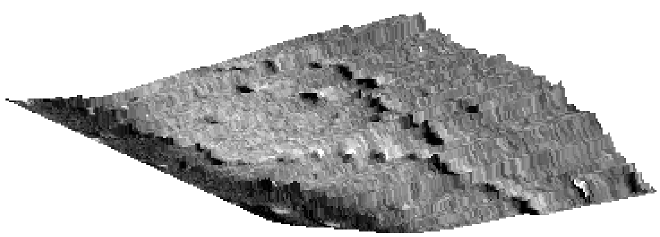

Fig.5. Results of seafloor shape reconstruction

Additionally, the developed algorithm was tested using synthetic aperture sonar data image with wreck. Sample of data image from synthetic aperture sonar was presented in Fig. 6. The results are presented in Fig 7.

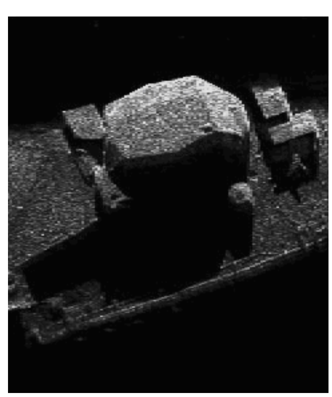

Fig.6. Data from synthetic aperture sonar

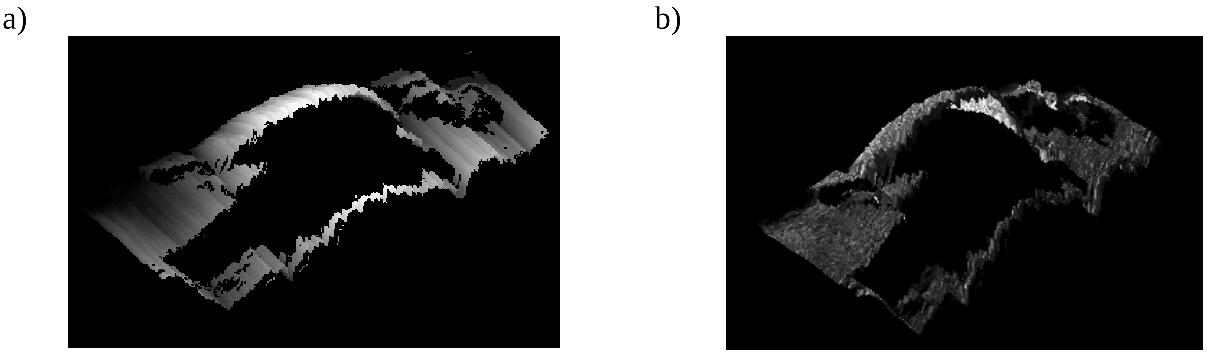

Fig.7. Results of wreck shape reconstruction

3. CONCLUSIONS

The method based on Shape from Shading (SFS) approach for 3^D reconstruction of seafloor and submerged objects shape from side scan and synthetic aperture sonar records was presented. The advantage of the presented method is their simplicity and the ability to produce the results within sequential, i.e. "one run" processing of side scan sonar data. The presented results are promising both in seafloor and wrecks shape reconstruction imaging. The future work should concentrate on implementation of more advanced both SFS and shadow processing algorithms. In particular, the authors predict that in the presented seafloor reconstruction algorithm, during sonar image processing, the performance improvement could be achieved by taking into account the information obtained not only from a current ping and one previous ping, but from a number of previously processed pings, combined for instance with the application of the weighted averaging technique.

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