3^D RECONSTRUCTION OF SEAFLOOR FROM SIDE-SCAN RECORDS

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The modern underwater acoustic equipment, like multibeam sonar, is able to provide the data which allows for unambiguous localization and also 3^D visualisation of targets of different kinds, including wrecks, mines and other submerged objects. The large amount of information that seems to be useful for this purpose, could also be extracted from side-scan sonar data, which has been collected over years within different survey regions. In this context, the paper concerns the development of side-scan data processing method for 3^D reconstruction of seafloor and its imaging. In this paper, two novel approaches are proposed. The first utilises the more accurate models of backscattering, including the differences in signatures of several types of objects. The second is based on definition and investigation of some quantitative descriptors of geometric features expected to be found in images of localised objects of artificial origin. The preliminary results obtained by application of these techniques to side-scan sonar data processing will be discussed in this paper.

INTRODUCTION

3^D visualization of the seabed has become increasingly important for many activities like the terrain and seafloor monitoring, pipeline tracking and mine hunting, etc. Among them there is also wreck visualization, the field especially attractive not only for acousticians but also for underwater archaeologists. Most of very attractive images of wrecks represent acoustic data obtained by modern multibeam systems, which allow for their 3^D visualization [1]. However, many 2^D images acquired by side-scan sonar systems exist, that could be transformed into 3^D representation in an algorithmic way using intensity information, contained in a grayscaled side-scan sonar images.

Several techniques of 3^D geometry reconstruction for seabed surface or submerged objects using side-scan sonar images has been reported [2, 3, 4, 5]. 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 [6] for a collection of significant papers on SFS). In the construction of the seabed elevation map from side-scan data, 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 [3] is often used as a model of the angular dependence of bottom scattering coefficient.

For wreck visualization, the above technique is not the most appropriate because it leads to obtaining very smooth shapes which differ significantly from actual forms of artificial objects. This paper presents the preliminary results of the proposed simple method of 3^D wreck shape reconstruction using SFS scheme with different types of backscattering coefficient angular dependence function and estimation of the elevation change using the dimension of acoustic shadow areas.

1. ALGORITHM DESCRIPTION

The developed procedure was tested on side-scan sonar data downloadable from Marine Sonic Technology, Ltd. site. The sample wreck image acquired by side-scan sonar is presented in Fig. 1.

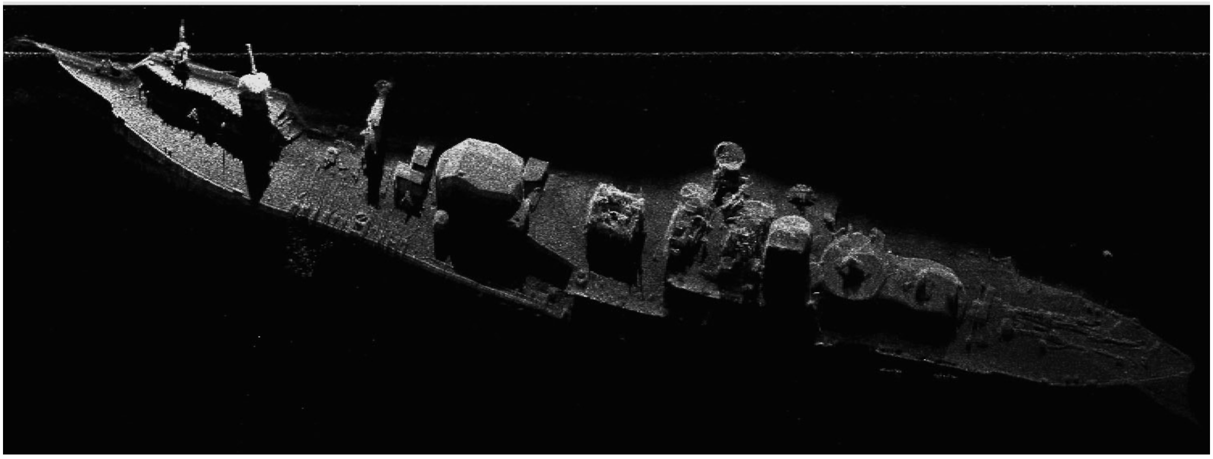

Fig.1 Image of the USS Utah, resting in Pearl Harbor near Ford Island, acquired by the U.S. Army 7th Engineer Detachment using Sea Scan Centurion system operated at 600 kHz.

The following assumptions were made for the development of the algorithm of wreck 3^D shape reconstruction: (1) acoustic wave propagates in water column along fairly straight line, (2) reflectivity model is known, (3) altitude h of the tow fish is known, (4) the normal of 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) and (5) the dimensions along vertical (z) axis of an object to be reconstructed are small in comparison with the tow fish altitude.

The geometry scheme used in the algorithm is presented in Fig. 2a. In an image obtained from side-scan sonar survey, each pixel belonging to a given line across survey track is a sample from an echo envelope at time point t_i and corresponds to a point P_i on seabed surface or submerged object. Its across-track co-ordinate can be estimated as follows:

$$x_i = \sqrt{\left(\frac{ct_i}{2}\right)^2 - h^2} \qquad (1)$$

where $t_i \geq \frac{2h}{c}$, c – sound speed in water.

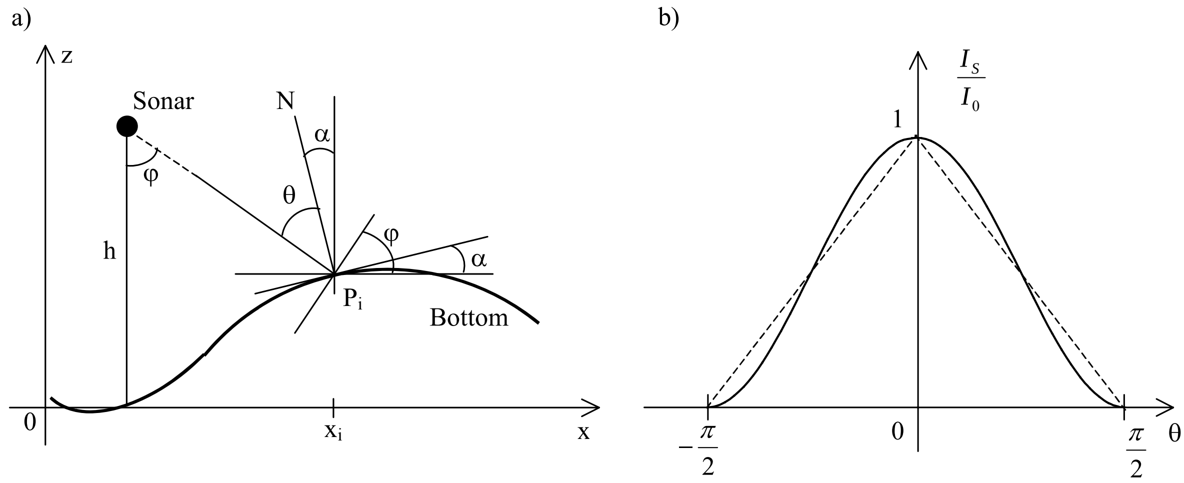

Fig.2 a) The geometry used in the algorithm: h – the sonar tow fish altitude, N - surface normal vector, α - bottom slope angle,θ - incidence angle;φ - transmission angle; b) two examples of assumed dependence of bottom surface backscattering coefficient.

The algorithm of the altitude (z co-ordinate value) estimation was applied separately to each line across the track in a processed side-scan sonar image, and may be summarized as follows: first, the initial z value z_0 was assumed. Second, if the currently processed i-th pixel was not recognized as the beginning of a shadow area (e.g. its intensity was above a chosen threshold value), the scheme based on SFS was applied, namely the local incidence angle θ_i was estimated from pixel intensity by inverting the backscattering coefficient angular dependence function. Two types of this function were concurrently used, viz: Lambert's Law-like (solid in Fig. 2b)

$$\frac{I_s}{I_{0s}} = \cos^2\theta\,, \tag{2}$$

and linear (dashed in Fig. 2b)

$$\frac{I_s}{I_{0s}} = 1 - \frac{2}{\pi}\theta\,. \tag{3}$$

The altitude z_{i+1} of the next point P_{i+1} was estimated using linear approximation as

$$z_{i+1} = z_i + \left(x_{i+1} - x_i\right)\tan\alpha_i\,, \tag{4}$$

where the surface slope angle α_i was calculated as

$$\alpha_i = \varphi_i - \theta_i\,, \tag{5}$$

where φ_i – local transmission angle estimated as $\arctan\left(x_i/h\right)$. Otherwise, the length of shadow area along x axis was calculated as $\Delta x = x_{j+1} - x_{i-1}$, where j – number of the last pixel in a currently detected shadow area, and then the altitude values from z_i to z_j were set to unknown, and the z_j+1 value (decreased) was calculated as

$$z_{j+1} = z_{i-1}\Delta x\tan\alpha_{i-1}\,. \tag{6}$$

2. RESULTS

The sample results of a wreck 3^D visualization, along with the illustration of several calculation stages for a selected sonar echo, are presented in Fig. 3 and 4, in which eq. (2) was used.

Fig. 3 presents the variability of several calculated quantities along *x* axis for one selected across-track line of pixels in the processed image. The visualization of the reconstructed 3^D model of submerged wreck is shown in Fig. 4a and 4b using the Virtual Reality Modeling Language (VRML). Since the 3^D co-ordinates (*x*, *y*, *z*) data has been obtained for an investigated object, its visualization can be easily made for various settings describing the 3^D view, i.e. the localization of the observer and direction of its sight, type of 3^D perspective etc.

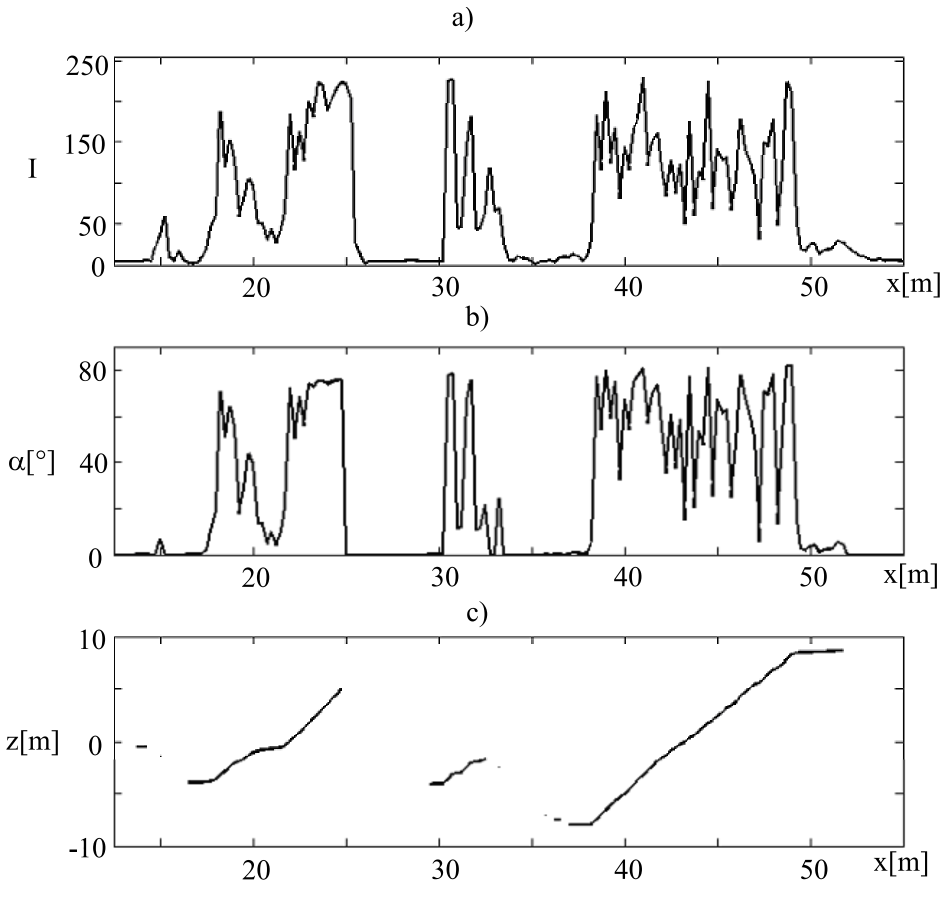

Fig.3 Different stages of the algorithm for a sample line of the processed image: a) pixel intensity variability along x axis, b) estimated slope angle variability along x axis, c) estimated altitude (no values estimated for shadow areas).

While comparing the result from Fig. 4 with the original flat image from Fig. 1, it is visible that the overall shape of the wreck has been preserved quite well, even for small details. The visible artefacts in a form of dark lines across the track are the result of processing the pings from the image having relatively small intensity values, e.g. under the applied threshold value. As a result the recognition of the whole line of pixels produces a shadow area.

3. CONCLUSIONS

The simple algorithm for 3^D wreck image reconstruction from side-scan sonar data was proposed and tested. The algorithm combines two techniques: the SFS scheme using backscattering coefficient angular dependence function and the estimation of the elevation change using the dimension of acoustic shadow areas. The presented preliminary results are promising as they show quite good performance of the developed algorithm. The future work should concentrate on implementation of more advanced both SFS and shadow analysis algorithms, which could also allow for weakening the used assumptions.

a)

b)

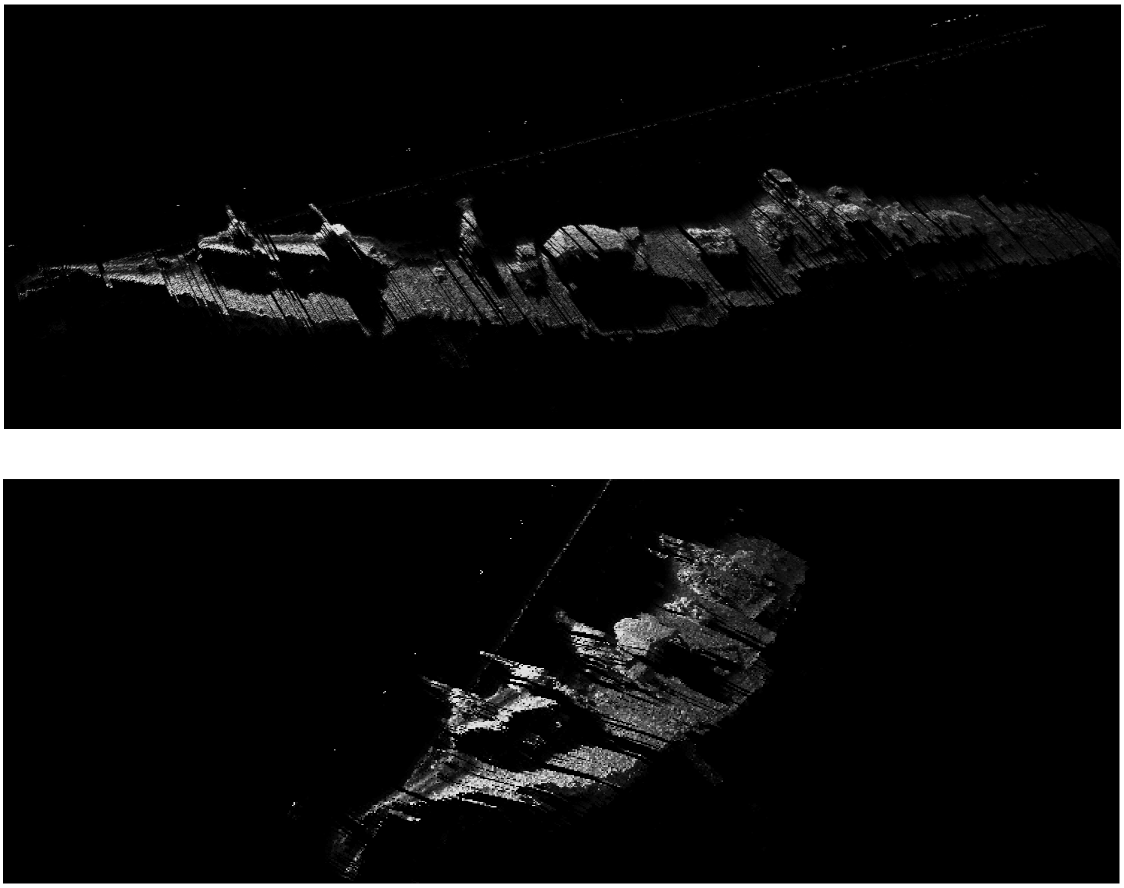

Fig.4 Two examples of the VRML visualization of the reconstructed 3^D model of submerged wreck from the side-sonar data presented in Fig. 1, with use of different view point settings.

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