3^D VISUALIZATION OF SEABED FROM MULTIBEAM SONAR RECORDS USING TRIANGULAR IRREGULAR MESH.

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ABSTRACT

Application of $\mathbf{3^D}$ imaging has been finding its place in many fields of marine science and technology and it has become almost indispensable tool in such areas like hydrography, marine navigation, seafloor mapping and characterization, marine GIS, ECDIS etc.
Contemporary seabed mapping/imaging systems employing processed bottom echo records, acquired by a multibeam sonar, can map the bottom with the meter resolution. However, despite these advantages, even after employing data preprocessing, the method results in the excessive amount of data and the warehouse of petabytes.

To address the problem of a compact representation of the huge amount of these raw data and an accurate seabed surface reconstruction from the multibeam sonar records, the paper proposes the data reduction algorithms developed for this purpose. The first one represents the smoothing procedure using B-spline surface obtained from a set of bathymetric $\mathbf{3^D}$ data retrieved from the sonar echoes. Whereas, the second one transforms the echo records to the discrete wavelet coefficients domain, and subsequently uses the wavelet shrinkage theory.

The second stage in both methods consists of decimation procedure, which reduces the number of polygons in the mesh, while maintaining the sufficient resolution and accuracy of the reconstructed seabed surfaces.
Both investigated methods seems to be quite promising tools for significant data reduction and compact representation of seabed $\mathbf{3^D}$ images retrieved from the sonar echoes.

INTRODUCTION

$\mathbf{3^D}$ seabed image with high spatial resolution can be relatively easy obtained from multibeam sonar bathymetry, but as a result a huge amount of raw data is produced. These have a raster character and are very close to digital terrain model DTM or DEM. Due to the high sampling rate and numerous sonar beams these data are very dense and makes data-set manipulation difficult and tedious.

To solve this problem the qualitatively different techniques should be considered where a bottom imaging models are perceived from the data. This new, rather inductive approach is called a common reverse engineering problem and lays in converting thousands points collected from the surface of seafloor via a digitizing process, into a coherent geometric model that can be easily transferred. This process in the form of successive transformation stages is presented in Fig.1. Three upper levels at that figure represent model which was perceived from the dense hydroacoustic data, the last level constitutes the tessellation or TIN (triangular irregular network) transformation which are always present in a computer imaging chain.

The objective which was undertaken in the investigation is transformation of a raw hydroacoustic data into the spline and wavelet representation and evaluation of performance of the applied methods. In both cases the raw hydoracoustic data from multibeam sonar are preprocessed into a such model that can be expressed in a mathematical way. As to spline theory it is generally the B-cubic polynomial representation and as to wavelet theory it is a set of coefficients of a carefully chosen base fucntions.

SPLINES SURFACE APPROXIMATION OF MULTIBEAM DATA FOR GENERATION OF 3^D IMAGES.

The two most common approaches of representing a curve or a surface are the implicit or non-parametric and the parametric method. The implicit method is a function which depends directly on the variables. In the parametric method each of the variables is a function of an independent parameter. So the parametric representation of a curve or surface is not unique.

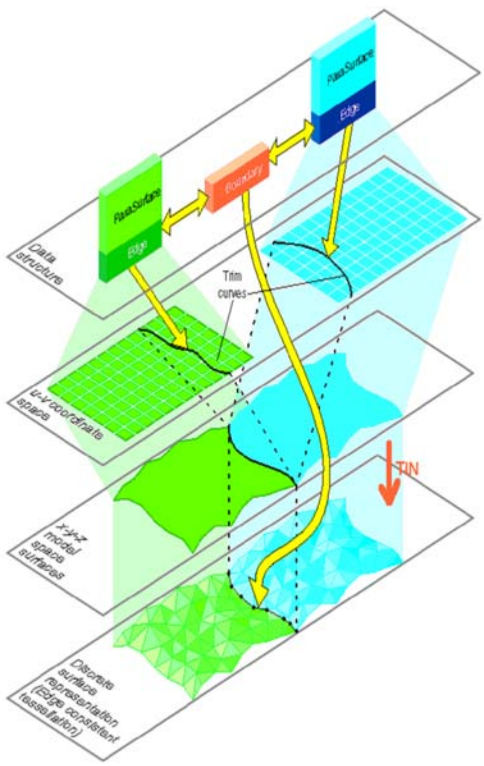

Fig.1.Spline model of sonar data for 3^D imaging of seafloor accord.[4].

It is commonly understood that the implicit methods based on splines using the B-spline representations provide the best tools for a geometry representation.

One of many ways of representing or modeling surfaces is via parametric surfaces such as B-Spline. This process is also called the surface fitting, (by analogy to the curve fitting) where surface models are generated by fitting points of polygonal meshes with least squares approximation. Usage of such representation enables to rebuild models, analyze properties of these models and to repair incomplete models. Mathematical representation of the same data with B-Spline surfaces is much more efficient both in memory requirement and facilitate of data editing.

Spline surfaces are direct generalizations of univariate splines and spline curves and enjoy many of the same properties. As in the univariate case, a tensor product spline is a collection of individual polynomial surfaces connected along lines called knot lines with certain continuity. Let orders k_u, k_v and knots $T=\{\tau_p\}_{p=1}^{P+k_u}$, $X=\{\xi_q\}_{q=1}^{Q+k_v}$ be given. The tensor product splines of order (k_u, k_v) with knots T, X are the functions f of the form

$$f(u,v)=\sum_{p=1}^{P}\sum_{q=1}^{Q} f_{pq}B_p(u)C_q(v)$$

where the functions B_p, C_q are the B-splines of order k_u, k_v respectively with the knots T and X. Thus, f is a function defined on the rectangle [3].

Polynomial splines representation applied to dense hydroacoustic data can be achieved in the following least square approximation methods:
- natural spline interpolation,
- complete spline interpolation,
- not a knot interpolation.

In this paper the first method was investigated.

2-D WAVELET MULTIRESOLUTION ANALYSIS OF MULTIBEAM DATA FOR GENERATION OF 3^D IMAGES

The 2D version of the Wavelet Transform (WT) by its definition expands any finite energy function $f(x,y)$ using a set of similar basis function $\varphi_{a,b}(x,y)$. Its continuous form description is defined as the inner product:

$$WT_{f,\varphi}(a_x,a_y,b_x,b_y)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\varphi_{a,b}(x,y)f^*(x,y)dx,dy$$

The basis functions are derived from each other by scaling and shifting one prototype function $\varphi(x,y)$ controlled by the parameters a_x, a_y, b_x, b_y respectively:

$$\varphi_{a,b}=\frac{1}{\sqrt{|a_x a_y|}}\varphi\left(\frac{x-b_x}{a_x},\frac{y-b_y}{a_y}\right)$$

Most discrete formulations of the two-dimensional wavelet transform (DWT) comprise a tensor product extension along with a dyadic scaling of the bases with $a_x = a_y = 2$ and unit shift $b_x = b_y = 1$. If any data set is transformed into wavelet space, it is necessary to find appropriate criteria to control the accuracy of the surface approximation provided by wavelet bases. This can be accomplished using the energy defined in L^2-norm, and due to the Parseval theorem, it equals the squared sum of wavelet coefficients. Thus, a simple criterion for the significance of particular wavelet coefficients is based on introducing a threshold to the coefficients and reconstructing the function $f(x,y)$ using filtered coefficients. The local support of the basis functions allows for localisation both in spatial and in frequency domain and rejecting a particular basis will only affect its area of support. This property enables an elegant control of the local of detail of the approximation. Using this idea, the algorithm was proposed [1] which estimates of the surface parameters using local detail signal of wavelet transform along with point removal and quadtree based meshing of the remaining surface points as shown in Fig. 2.

RESULTS

The data were collected with SeaBat 8101 multibeam sonar having following parameters: operating frequency 240 kHz and a swath wide coverage 150 degree, up to 300m range capability and implemented phase and amplitude bottom detection methods. Range resolution was 1.25cm and maximum update rate was 30 swaths per second with 101 beams of size 1½° x 1½°.

The sets records acquired on Baltic Sea were stored in the file as X, Y, Z coordinates and expressed in UTM coordinates. As an example, around 333 scans each having 60 sounding points were triangulated, resulting 40358 triangles. An excerpt from this data was sampled in regular grid and decomposed by means of wavelet transform DWT (see Fig.2a). The wavelet coefficients were zeroed on successive levels of transform followed by reconstruction as presented in Fig. 2b, which shows level of detail (LOD) approach by such multiresolution analysis [1]. The same data sets were chosen for evaluation of a two dimensional spline least square approximation.

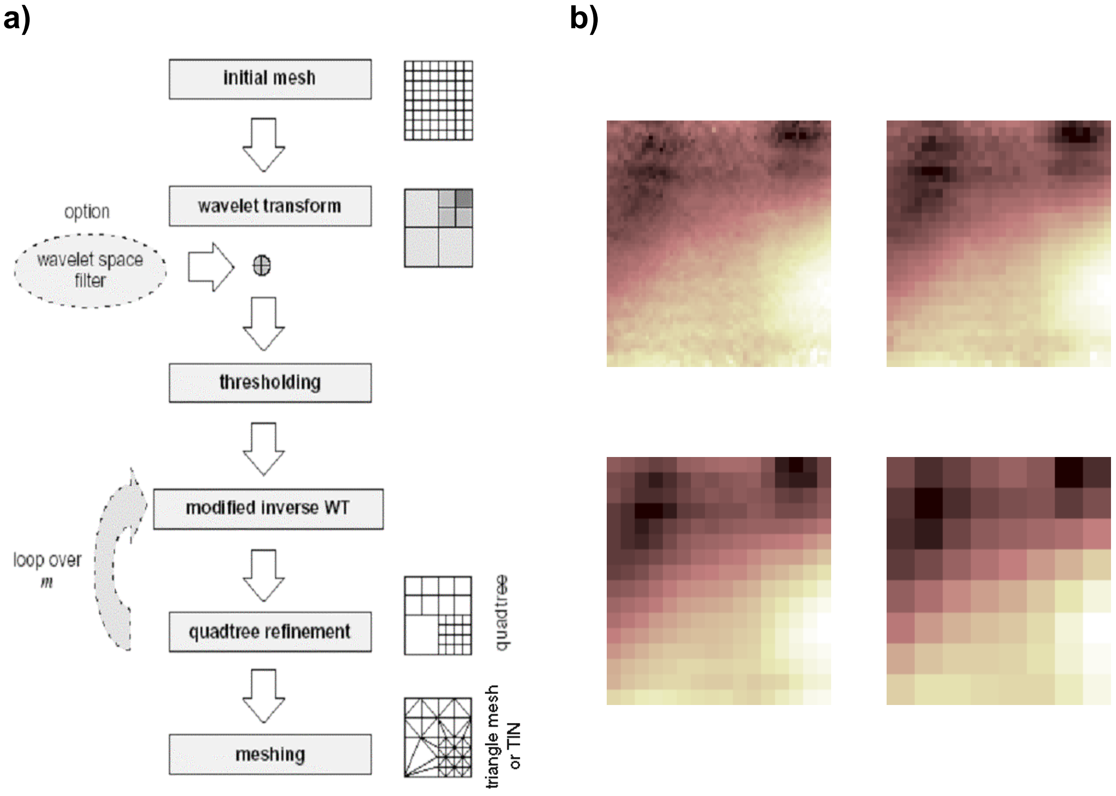

Fig.2. Algorithm of efficient triangular surface approximation using wavelet and quadtree data structures meshing (left). Level of detail (LOD) representation of sea bottom image (right).

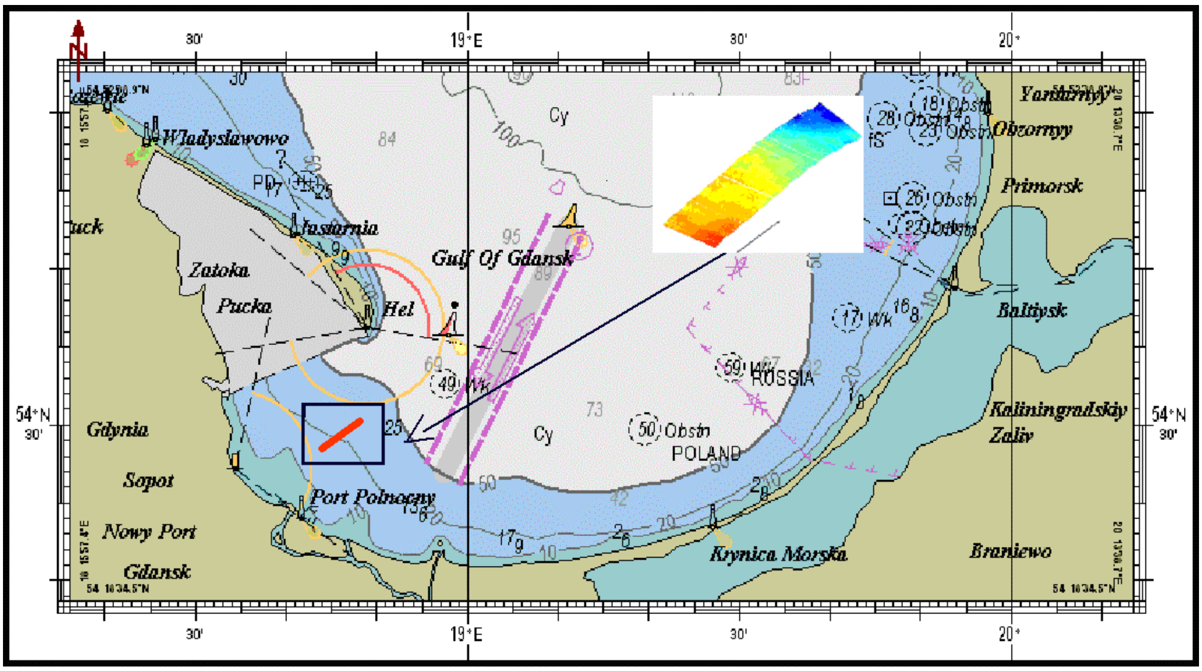

Fig.3. Data acquisition site (Gulf of Gdańsk)

a) **b)**

c) **d)**

e) **f)**

Fig.4. Perpendicular projection and related **3^{D}** visualization of: raw data retrieved directly from multibeam sonar transect (a, b), post processed data with spline approach after two times decreased raw data resolution (c, d) and postprocessed data with wavelet technique after first level of data reduction in a multiresolution scheme (e, f).

The sample of Gulf of Gdańsk where seafloor data have been acquired by multibeam sonar is presented in Fig.3. and Fig.4. They show perpendicular projection and related **3^D** visualization of raw data and data, which were processed by spline least square approach and wavelet 2^D technique.

CONCLUSIONS

Convenient spatial representation is essential in seafloor visualization process. It can facilitateand accelerate data analysis and both methods of 3D seabed visualization viz.: splines and wavelets approximation seems to be very promising, as significant data reduction can be achieved by usage of spline and wavelet application to the multibeam sonar records.

Raw data obtained from multibeam sonar are affected by many artifacts like spikes, but when a spline approximation is applied despiking/filtering is applied automatically in the same time, which was shown in Fig.4d.

The data obtained from adjacent transects are relatively easy merged especially splines manages this process in a very efficient way.

In a well structured seabed spatial database, attributes can be assigned to spline suface objects which can represent a sample of raw data, as shown on the first layer in Fig.1.

The paper also shows that the "zooming in" or LOD ability allows the use of "just enough" precision in a given region of interest while at the same time allowing coarse representations in regions. Spline surface approximation process does not need a regular mesh grids of data as the system input, in contrary to wavelets. However both processes are time consuming what is an obvious drawback in real time systems.

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