Multibeam data processing for 3D object shape reconstruction

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The technology of hydroacoustic scanning offers an efficient and widely-used source of geospatial information regarding underwater environments, providing measurement data which usually have the structure of irregular groups of points known as point clouds. Since this data model has known disadvantages, a different form of representation based on representing surfaces with simple geometric structures, such as edges and facets, is preferred for data featuring seabed surface relief and various underwater objects. In this paper, the authors propose a multiple-step approach to three-dimensional surface reconstruction from multibeam sonar measurements, relying on the proper application of various algorithms for noise reduction, data rasterization and classification. The results obtained by combining several different surface reconstruction algorithms with the proposed data processing technique were tested, and the strengths and weaknesses of each method were highlighted.

Keywords: multibeam sonar, 3D reconstruction, point cloud, wrecks, rasterization

1. Introduction

Studies related to marine underwater environments often utilize the technology of hydroacoustic scanning, such as single and multibeam echo sounders [1][2], side-scan sonars [3] and acoustics cameras [4], which offer the ability to obtain valuable information on the shape of the seafloor and various underwater objects. The spatial data acquired with these methods have a wide range of applications, such as providing assistance related to safe navigation in underwater environments, investigating and visualizing 3D underwater objects [3] such as shipwrecks, modelling various processes occurring in shallow and deep waters, performing geological research and recognizing topographical features in the seabed, as well as monitoring and imaging of underwater environmental pollution [5][6]. The aforementioned spatial data usually describe the shape of researched objects in the form of irregular groups of points known as point clouds. Unfortunately, this data model has notable disadvantages, i.e.:

I.   Spotting some features may be difficult if the point cloud density is too low, which sometimes requires that the data is viewed from very specific angles.

II.   On the other hand, if the point density is high, then this causes unnecessary redundancy when representing uncomplicated surfaces, which leads to large increases in the requirements for disk storage and system memory.

For the above reasons, a better solution for visualizing underwater objects, such as seafloor and shipwrecks is to use a data model based on representing surfaces with simple geometric structures, such as edges and facets, which offer simplified visualization and better processing performance.

There exist a large number of solutions used for recovering the surface of data obtained by side scan sonars and multibeam echo sounders, including commercial software such as the Kongsberg Seafloor Information System (SIS) [7] or QINSy Software [8], however their approach usually relies on applying uncomplicated and straightforward shape reconstruction algorithms, which are suitable for surfaces such as seabed, but often lead to creating a large number of artifacts when applied to data describing complex objects. At the same time, very few attempts for recovering high quality meshes from underwater objects are reported in literature. Bikonis et al. [9] created a method of generating 3D wreck models from multibeam data based on analysing the adjacency of points in a point cloud, and detecting the acoustic shadow zones. Lu et al. utilized bathymetric data to acquire a reconstructed model of the seafloor by dividing the data into smaller sectors, applying the Delaunay triangulation in each sector individually, and merging the divided data into a single triangulated mesh [10]. Hurtós et al. presented a method for recovering underwater environment scenes by combining data from acoustic and optical sensors [11]. Mosca et al. [12] proposed a method of imaging the sea bottom and visualizing fishschool structures in 3D, to offer aggregated information on fishing areas. On the other hand, the work on recovering underwater surfaces from side scan sonar data is very well reported. Y. Lu and M. Oshima [13] presented a 3D shape reconstruction method based on image matching to obtain stereo-like vision approach from multiple sidescan sonar images obtained from different viewpoints. E. Coiras and Y. Petillot [14] proposed a method for estimating seabed elevation from side-scan sonar images where the image formation process is based on a Lambertian diffuse model, inverted by an optimization technique. A similar approach was also applied in [15], where the proposed solution is based on the Shape from Shading method for estimating the gradient of local seabed surface altitude, where the seabed surface scattering model is obtained by analysing subregions of sonar images corresponding to flat, or nearly flat, seabed.

The aforementioned methods are dedicated mainly to visualizing simple models, such as the seafloor. A large number of robust algorithms also exist for creating 3D meshes of more complex objects from point cloud data [16][17][18][19]. Unfortunately, when applied to data obtained by acoustic sounding techniques, these methods often generate unsatisfactory results, caused by problems such as the existence of significant amounts of noise, as well as strong variability of data accuracy and local point density. R. Campos, R. Garcia and T. Nicosevici have proven that some of these methods offer satisfactory results for reconstructing the surface of several underwater areas [20]. However, achieving a similar reconstruction quality for more complex objects is a much more difficult task [21][22]. Because of this, the application of a new solution for surface reconstruction of underwater data may enable the creation of more accurate models of the researched objects, which could be used in various software offering the visualization of 3D objects and scenes, such as geographic information systems. A new approach to three-dimensional surface reconstruction of multibeam data is presented in this paper, largely based on various pre-processing methods.

Data description

The input data has been acquired by measuring the seafloor with the use of multibeam echo sounders; and thus have the form of geospatial 3D point clouds describing the approximate shape of the seabed, as well as various other objects located on its surface. The data used in this work originates from various sources, such as:

- Dr. Krzysztof Bikonis from the Department of Geoinformatics, Gdańsk University of Technology,
- Maritime Office in Gdynia, Poland,
- Kongsberg Maritime AS, Kongsberg, Norway.

Despite being obtained by different people and tools, the spatial structure of the acquired data is similar among different datasets and consists of unorganised groups of point clouds with varying density, Since the method used for acquiring the data relies on the use of vehicles which gather the data while remaining at the same altitude (water level), the surfaces which are parallel to the vehicle's track of movement are represented in greater detail than other surfaces.

2.   Data processing methods

The approach presented in this paper relies on performing several different steps of processing the input data prior to the actual surface reconstruction. The overall workflow of this solution is shown in Fig. 1.

The pre-processing step of the solution consists of converting the input data from unorganized point sets into regular raster grids, which not only simplifies the further steps of the processing pipeline, but also makes it possible to use shape reconstruction algorithms designed to work in two-dimensional spaces, since the modified data can also be treated like a two-dimensional point set [23]. An additional noise reduction step is performed during this process, dedicated to specific types of irregularities, such as data incompleteness and strong variability of local point accuracy.

Another important step performed before shape reconstruction is based on adding classification information to the modified data by detecting large individual objects and assigning them to different groups of points, since data classification can significantly improve the quality of various shape reconstruction algorithms applied to underwater objects [21]. The classification algorithm is divided into three parts:

I. Creating a copy of the modified point set, and smoothing its shape by processing it with the median filter, removing any remaining local irregularities which could affect the further steps of the algorithm. The filtered copy of the data is only used as reference during the classification process.

II. Preliminarily dividing the data into two classes, based on the following delimiter: any points located below a set value (passed as a function parameter) of the dataset's height delta are assigned to class 0 (the seafloor), while all other points are assigned to class 1 (other objects). The default value of the delimiter is equal to 10%, as it is satisfactory for data describing large underwater objects like shipwrecks. For data describing only the seabed, the algorithm should eventually assign all points to class 0.

III. Correcting the previously established classification by continuously checking points located on the borders of class 0 and comparing them with neighbours assigned to class 1: if the height difference between two neighbouring points from separate classes is small enough (by default it is 5% of the dataset's height delta), then the point from class 1 is also assigned to class 0. This step is performed repeatedly as long as there are still points which can be classified as the seafloor.

IV. Iterating through every point assigned to class 1, and detecting isolated groups of points which are surrounded by points classified as seabed, and assigning them to new classes, so that each individual object in the data is given a unique class.
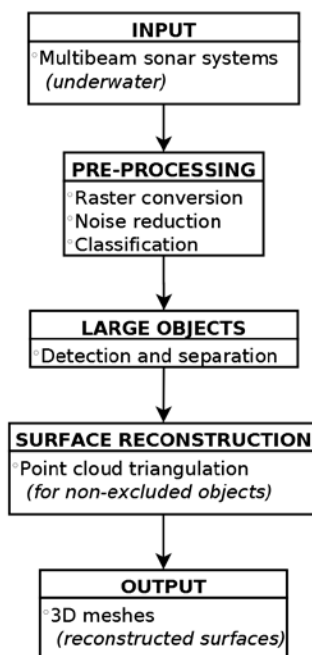

Fig. 1. The flow chart of the proposed solution.

Figure 2 shows the results of applying the first three steps of the classification method applied to sample point cloud data describing seafloor with shipwrecks (Fig. 2 a). Fig. 2 b presents initial classification of the data, with the points assigned to class 0 being hidden. Fig. 2 c shows the contents of class 1 after performing classification correction.
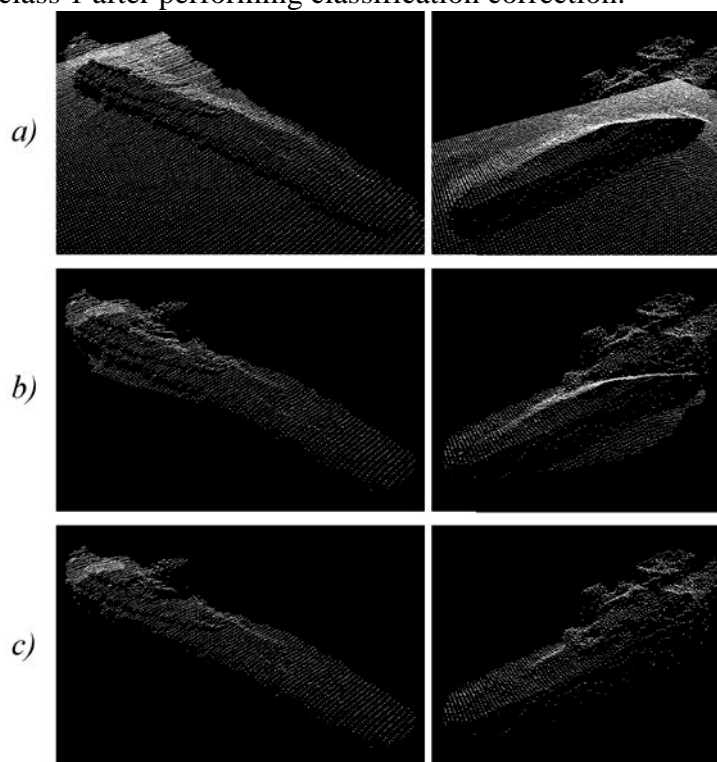

Fig. 2. The results of applying several steps of the classification algorithm, used for extracting shipwrecks from data describing the shape of seabed.

The surface of each classified object is reconstructed by applying a specialized algorithm which accepts properly pre-processed regular data as input, analyses each row of the data, and iterates through every point in that row and compares their heights with heights of points located in the neighbouring row. The algorithm then creates triangles on top of these groups of points where its members all share similar heights. After that, the algorithm iterates through the data once more to fill any remaining holes located between previously added triangles.

3.   Results

The results of applying the processing methods described in paragraph 3 to two different datasets are presented. Additionally, the results obtained by the proposed triangulation method are also compared with the results of using several widely-known surface reconstruction methods.

Fig. 3 shows the results of applying four different shape reconstruction methods to a sample dataset describing a fragment of seafloor featuring a single shipwreck. The result obtained with Poisson surface reconstruction provided a simplified mesh featuring very little details (Fig. 3 a). The Delaunay triangulation algorithm created an irregular yet detailed model, which also features additional polygons noticeable on the sides of the shipwreck (Fig. 3 b). The Ball Pivoting method generated an overall-regular model, but also featuring a large number of holes (Fig. 3 c). The proposed reconstruction method created a mostly regular mesh featuring an (overall) large number of details (Fig. 3 d). For reference, Fig. 3 e) shows the classified point cloud data to which the aforementioned algorithms were applied.
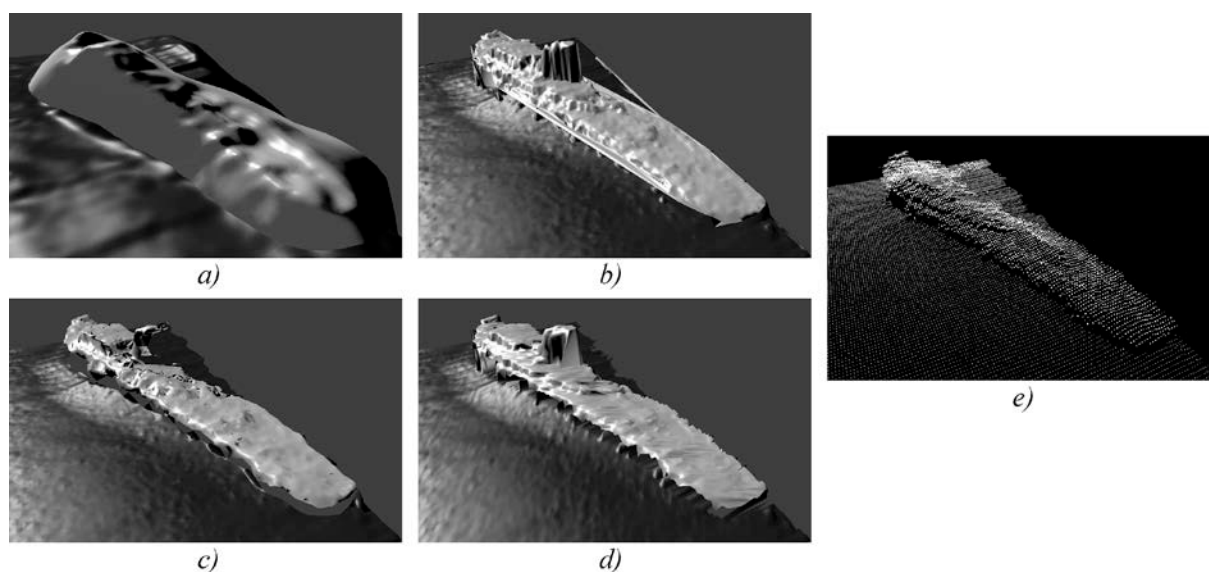

Fig. 3. The results of applying several shape reconstruction algorithms (a: Poisson Surface Reconstruction, b: Delaunay triangulation, c: Ball Pivoting, d: proposed triangulation method) to sample data (e) describing a single shipwreck separated from the seabed.

Fig. 4 shows the results of applying the same methods to a similar dataset with better resolution, but also a larger amount of irregularities. This time the Poisson surface reconstruction method managed to capture all important features of the data (Fig. 4 a), although the overall shape of the created mesh lacks any details. The Delaunay triangulation algorithm once again created an irregular model featuring all important details, although some distortion is visible in the lower part of the shipwreck (Fig. 4 b). The Ball Pivoting method generated a detailed mesh containing a significant number of holes (Fig. 4 c). The proposed

surface reconstruction method created a model which features all important details, although also featuring several irregularities in the lower parts of the shipwreck area (Fig. 4 d). The classified point cloud data used for testing the aforementioned algorithms can be seen in Fig. 4 e).
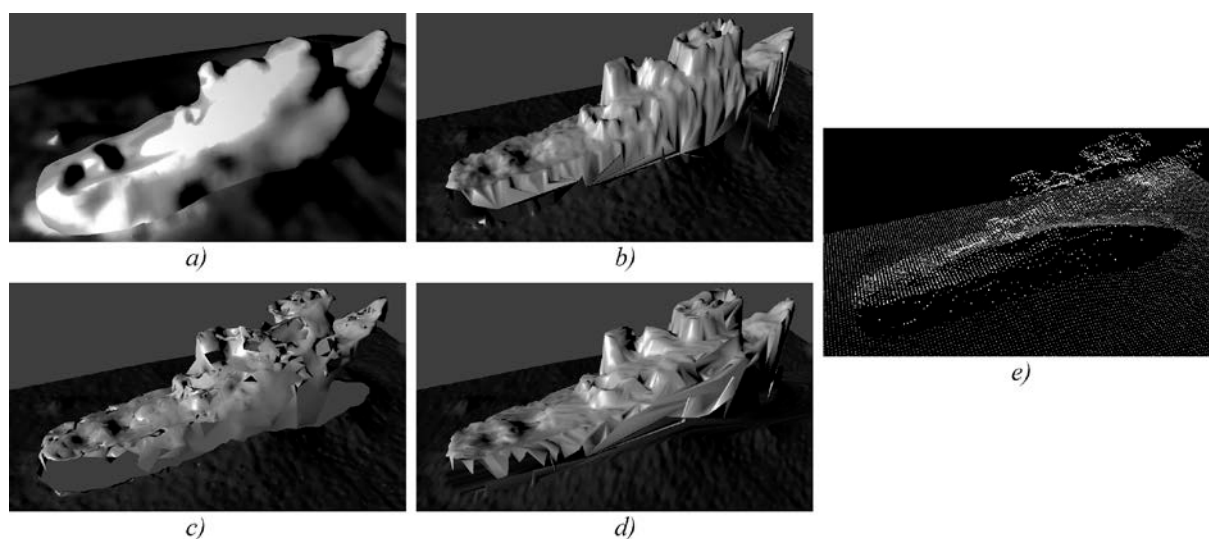

Fig. 4. The results of applying several shape reconstruction algorithms (a: Poisson Surface Reconstruction, b: Delaunay triangulation, c: Ball Pivoting, d: proposed triangulation method) to sample data (e) describing a single shipwreck separated from the seabed.

4. Conclusions

An approach for surface reconstruction of underwater data using a multiple step preprocessing method was presented and tested on sample data. Although this solution is dedicated to data acquired by multibeam sonars, it should also be adaptable to other sources as long as the data has a similar structure. Several different surface reconstruction methods were also tested in combination with the proposed data processing techniques, and compared with the proposed triangulation method.

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