RECONSTRUCTION METHODS FOR 3D UNDERWATER OBJECTS USING POINT CLOUD DATA

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Existing methods for visualizing underwater objects in three dimensions are usually based on displaying the imaged objects either as unorganised point sets or in the form of edges connecting the points in a trivial way. To allow the researcher to recognise more details and characteristic features of an investigated object, the visualization quality may be improved by transforming the unordered point clouds into higher order structures. There are many algorithms for constructing meshes from point clouds, some of which are more suited to processing data obtained from particular sources. This article presents the application of several methods for generating 3D models from point clouds for the purpose of reconstructing underwater objects, such as shipwrecks. The article presents the results obtained with each method and discusses possible ways of improving the quality of produced meshes.

INTRODUCTION

One multibeam sonar application detects, images and recognises underwater objects like shipwrecks. Usually, multibeam systems deliver data on seafloor relief or underwater object shape in the form of a georeferenced file consisting of a cloud of points. The points are located in the three-dimensional space XYZ, which can be used for reconstruction of the original shape. In the context of imaging underwater objects, the approach based on the visualisation of a point cloud itself as an unorganised set of points, or generating the edges connecting the points in a trivial way (e.g. simply connecting the points corresponding to successive beams in one ping), does not provide satisfactory results. For instance, Fig. 2a presents a ship wreck point cloud visualised as a set of curves, where each curve corresponds to a single piece of ping data. In order to obtain a better quality of visualisation, which would allow the researcher, for example, to recognise more details and characteristic features of an investigated object, a more advanced approach is needed. The approach should rely on the appropriate construction of the three-dimensional model of an imaged object composed of higher order geometric structures, e.g. consisting of such elements as points (nodes), lines (edges) and plane elements (facets).

The problem of reconstructing an accurate shape of an object from discrete measurements has been discussed for many years and a wide variety of methods have been proposed to solve it. That said, few of these methods have been applied to recovering 3D models of underwater areas. Those that have been tested in such circumstances have either been proven to produce noisy output which could not be used for further work ([1]) or were used for surfaces which did not contain large underwater objects such as shipwrecks (see e.g. [2] and [3]). This paper presents a test of the performance of some of the latter methods when applied to point clouds measured by multibeam sonar. The methods have been briefly described in the next section, while the two following sections present and discuss the obtained results and propose certain methods for improvement.

1. SURFACE RECONSTRUCTION METHODS

In literature, the methods used for reconstructing a surface from a set of points are classified in different ways depending on the author decision. In this paper, the points have been grouped into two categories depending on their method of interaction with the data.

The first group of algorithms consists of methods which use the 3D input points as the only source of information required in the reconstruction process. In other words, these methods will always process input data as an unorganised set of points, ignoring any additional information. One of the more notable methods is the Ball-Pivoting algorithm, which is a region-growing solution [4]. As its name suggests, its concept is based on the idea of a ball which pivots around each edge of the current mesh boundary until a new point is hit by the ball. If the new point satisfies the criteria defined by the algorithm, it is then used to define a new triangle which is added to the mesh. Unfortunately, the quality of this solution is heavily-dependent on the parameters chosen by the user (such as the ball's radius), which have to be adapted for different areas and types of objects by means of trial and error. Another algorithm of triangulating an unstructured point set is the Poisson surface reconstruction method [5], which is based on constructing an approximate indicator function (using a Poisson equation in this case) defined as 1 at points inside the model and 0 at points outside. However, this solution requires that the input points are spatially-oriented, meaning that the inward-facing normal of each point must be calculated in advance. For this reason, the results obtained by this method are heavily-dependent on the way the normals are generated for the input data. The last of the methods presented in this category is the Power Crust algorithm [6], which uses a skeletal shape representation of the mesh to define the object as a union of balls centered at the inner medial axis, approximated with the use of the Voronoi diagram. Unlike the previous methods described in this section, this algorithm works in a fully automated fashion, meaning that it does not require the user to input any additional data besides the point cloud itself.

The second family of methods represents algorithms which are primarily used in the field of surface reconstruction limited to two, or two and a half dimensions. The idea behind using them for the process of recovering the shape of underwater objects is that the input data obtained by probing the seafloor is usually organized in a structure similar to a two-dimensional raster image. The most well-known method in this field is probably the Delaunay triangulation algorithm [7], which turns a point set into a triangulated mesh in such a way that for each computed triangle it is possible to create a circle which contains (meets) all of its points and does not contain any other points from the dataset in its interior. The other method in this category is based on converting the point set into a height map [8], thus it will be referred to in this article as the “Height Map” technique. Using this method, the input dataset is turned into a regular grid by resizing the existing lists of points so that the number of points per list would be constant. The height of each point is calculated by linearly interpolating the proper values between the original points. The dataset is then triangulated in a trivial way, where each set of four points is turned into two triangles if there are no other points between them. The concept of this method is explained in Fig. 1.

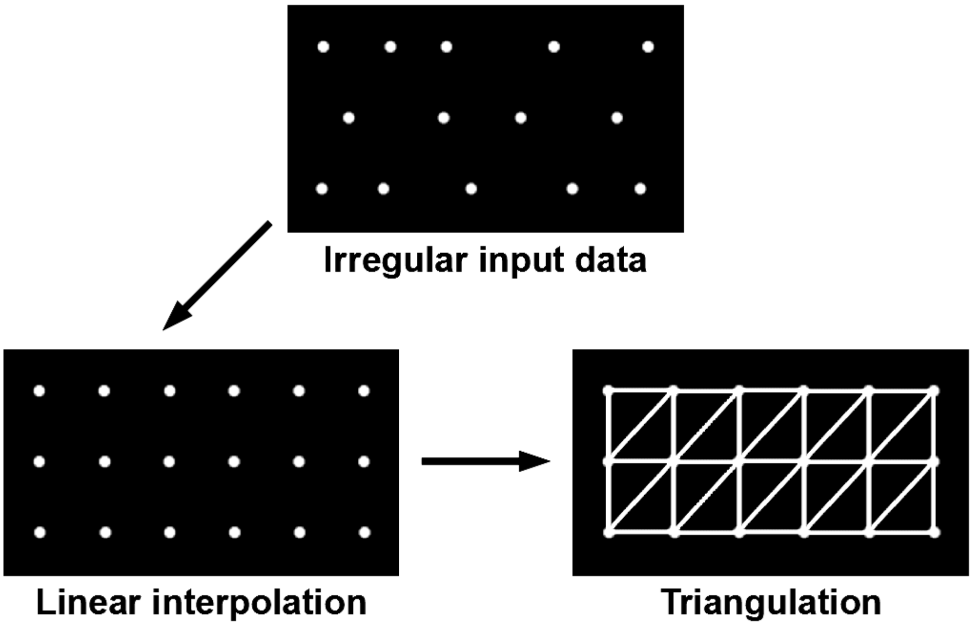


Fig. 1. Height Map technique explanation. The input dataset is converted into a regular grid, where the height of each point is calculated by linearly interpolating the height of its neighbours. The converted dataset is then turned into a triangulated mesh.

2. METHOD IMPROVEMENTS

Although the surface reconstruction algorithms described in this paper are quite robust, they do not always guarantee satisfactory results, as shown in the later part of this article. Some methods have problems handling the input dataset if it contains objects with very different characteristics, such as local point density varying throughout the dataset. In some cases the method quality can be improved if prior to the reconstruction process the data is divided into smaller parts representing significantly different objects. After classifying the data, each object can be reconstructed independently from the others, minimizing the risk of the reconstruction algorithm making obvious mistakes, such as creating unwanted holes in the model or merging different objects into a single mesh.

It is worth mentioning that the datasets obtained by probing the seafloor usually contain a considerable amount of noise caused by scattering characteristics of the underwater environment. For some algorithms this noise adversely affects the final shape of the reconstructed objects. The quality of 3D reconstruction methods can be improved by filtering the data before applying the reconstruction procedure. Unfortunately, noise reduction also carries the risk of removing important details from the reconstructed objects.

3. EXPERIMENTS AND RESULTS

In our research we used the mentioned above reconstruction methods to convert a sample bathymetry dataset obtained by a multibeam echo-sounder system to organised structures of points, edges and facets describing 3D shapes. The file we used is composed of lists (lines) of points representing an underwater region containing the Cleona shipwreck, where each list (swath) corresponds to a single multibeam pinging. The dataset used in the investigation is shown in Fig. 2a, seen from a convenient angle for human observers. The other parts of Fig. 2 represent the results of applying different surface reconstruction methods to the sample dataset. The results shown are the best ones, obtained by empirically fine-tuning the available parameters upon which the different methods depend.

It may be seen that some of the algorithms have trouble reconstructing the entire surface. For instance, the Ball-Pivoting algorithm creates a surface containing many holes, as shown in Fig. 2b, which is caused primarily by the fact that different algorithm parameter values should be chosen for both the shipwreck and the seafloor, which is impossible when the mesh is treated as a whole. On the other hand, the Poisson surface reconstruction algorithm handled the data quite well (Fig. 2c), even though its quality is also heavily dependent on the parameters chosen by the user and picking the best parameters was not very intuitive. The best results were obtained by inverting the orientation of pre-calculated normals before applying the reconstruction algorithm and flipping them again after the processing was complete. Nevertheless, the reconstruction quality was not perfect either, as the algorithm failed to preserve some of the details visible in the original point set, such as the masts on the shipwreck, and it also created additional faces near the boundaries of the mesh. The worst results were obtained by using the Power Crust algorithm (Fig. 2d), which is probably caused by the fact that this method endeavours to find and approximate the closed surface which is absent in the dataset. Simpler methods, such as the 2D Delaunay triangulation (Fig. 2e) and the Height Map technique (Fig. 2f) were most successful in recovering the details of the seafloor, but they also could not properly handle the noise present in the shipwreck.

The procedures mentioned above have been applied again to the same data with the following modification. Prior to the proceeding with a given shape reconstruction method, the dataset of points was divided into two parts, namely, the shipwreck and the seafloor, as seen in Fig. 3a. Afterwards, each part of the model was reconstructed separately, picking best a given method parameter values for each object individually. This approach allowed for a significant improvement in the results obtained using the Ball-Pivoting algorithm (Fig. 3b). It may be seen that the reconstructed mesh now contains fewer holes in the seafloor, and even the shipwreck's mast has been approximately reconstructed. The same kind of improvement is also visible in the shipwreck model created by the Poisson surface reconstruction algorithm (Fig. 3c), although the masts have not been preserved as well as in the example of the Ball-Pivoting algorithm result (Fig. 3b). Once again, the worst results were obtained using the Power Crust algorithm (Fig. 3d), for the same reasons as mentioned before. Finally, the meshes created by 2D Delaunay triangulation (Fig. 3e) and Height Map (Fig. 3f) algorithms are very similar to the ones presented in Fig. 2, however this time the shipwreck model is no longer merged into the seafloor.

Additionally, a simple noise reduction filter was applied to the divided object shown in Fig 3a after converting it to a height map, but prior to applying the triangulation procedure. The filter removes all points located inside the model and preserves only the ones located on the model's outer faces. This was achieved by detecting areas where the amount of noise was significantly larger than in other parts of the dataset and preserving only the points which are placed highest above the seabed, filling holes between them where necessary. The result of this operation can be seen in Fig. 4b and it is clear that this method offers generally better reconstruction quality than basic triangulation on a noisy dataset as shown in Fig. 4a.

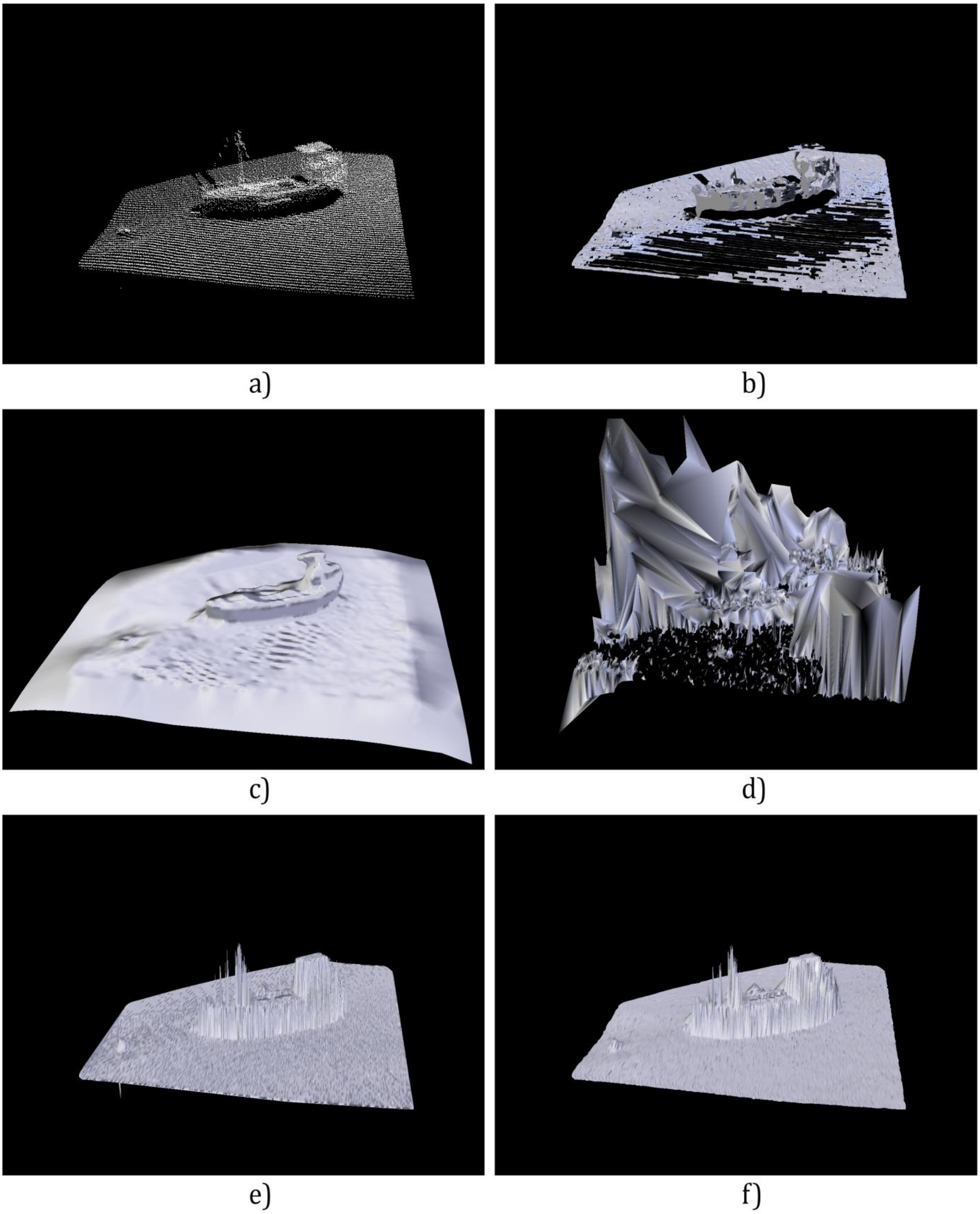


Fig. 2. The experimental results of applying several methods for 3D wreck shape reconstruction: input point cloud obtained by multibeam sounding (a) and reconstruction results obtained by Ball-Pivoting (b), Poisson method (c), Power Crust (d), Delaunay triangulation (e) and Height Map conversion (f).

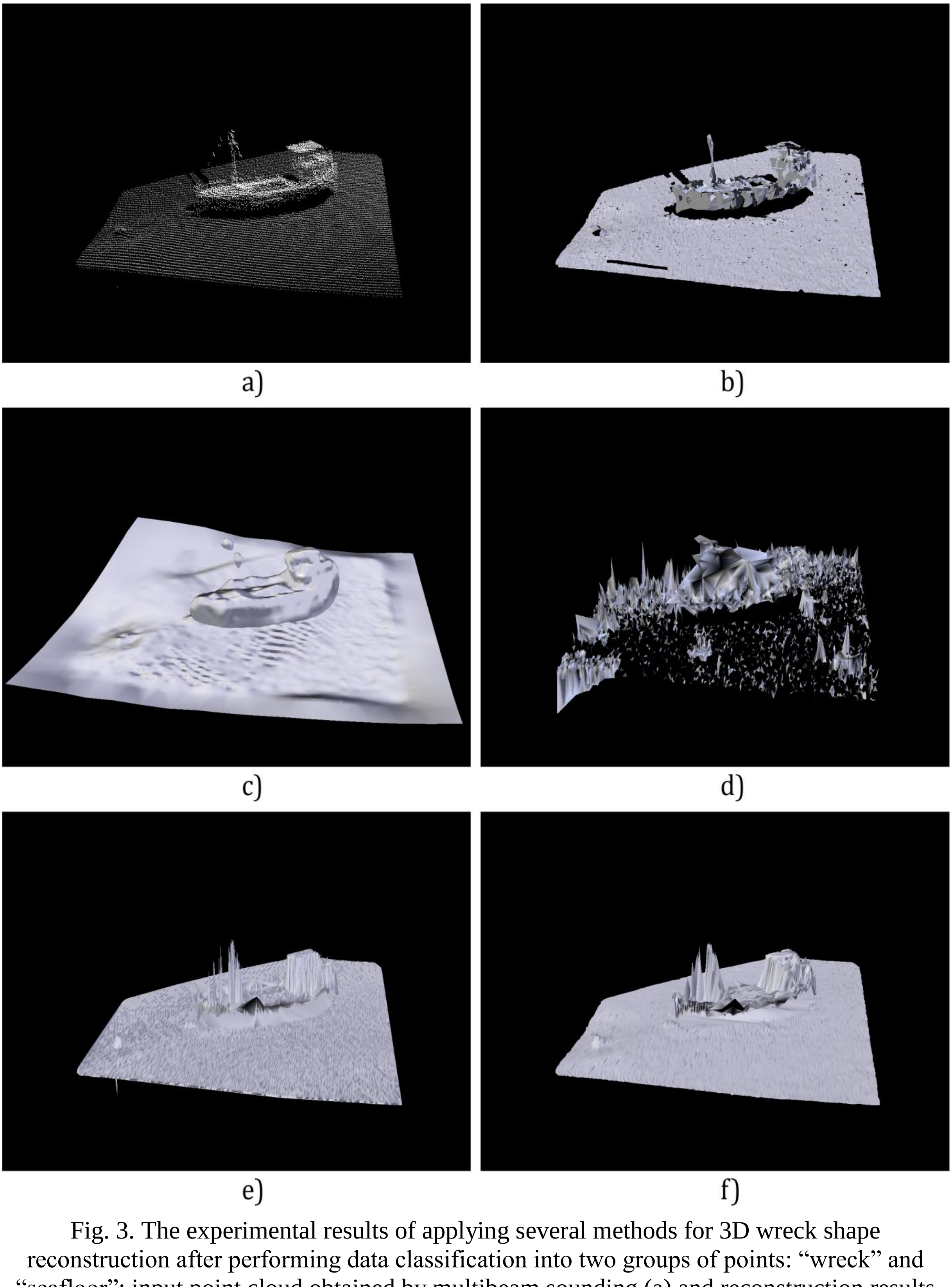
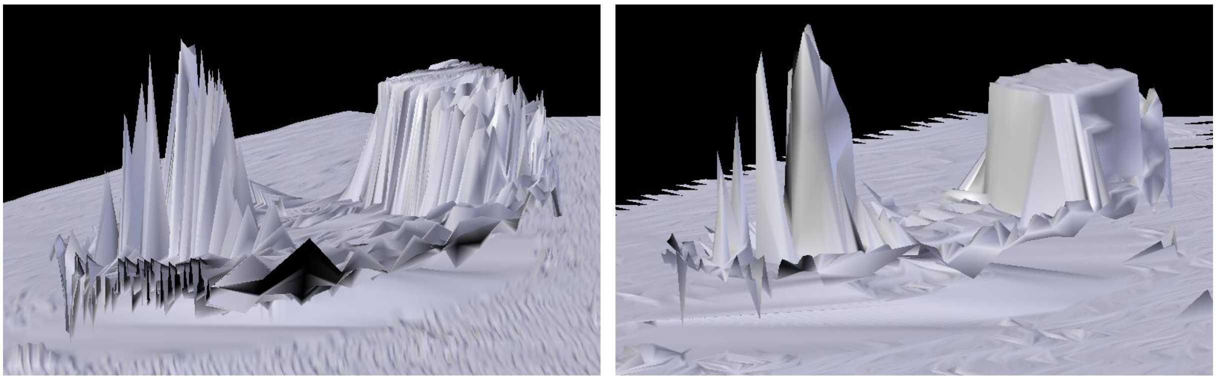


Fig. 3. The experimental results of applying several methods for 3D wreck shape reconstruction after performing data classification into two groups of points: “wreck” and “seafloor”: input point cloud obtained by multibeam sounding (a) and reconstruction results obtained by Ball-Pivoting (b), Poisson method (c), Power Crust (d), Delaunay triangulation (e) and Height Map conversion (f).



a) **b)**

Fig. 4. A comparison of the Height Map triangulation when applied to unfiltered (a) and filtered (b) data.

4. CONCLUSIONS

The problem of reconstructing the 3D shape of underwater objects from hydroacoustic measurements has been investigated. Several algorithms for creating meshes from unorganized point clouds have been applied for the purpose of reconstructing sample objects, such as shipwrecks, from multibeam sonar data. It was shown that existing methods provide insufficient results due to problems encountered handling underwater objects with multibeam point cloud representation. The reconstructed surfaces are either incomplete or have a very irregular shape. Subsequently, it was shown that when using the mentioned methods, the visualization quality may be improved by performing data classification and noise reduction prior to proceeding with a given method. These results are promising but it should be also pointed out that in the case of the implementation of the proposed approach in a real-time scenario of an in-situ visualisation of investigated underwater objects, the dedicated methods for automatic data classification along with surface reconstruction using multiple algorithms is be required.

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