

# 3D Data Processing for Underwater Inspection and Monitoring

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**Abstract** – Ever-growing attention has been given to the monitoring and inspection of underwater man-made structures for scientific and technical purposes. However, most of the related tasks are still involving the use of scuba divers.

In this paper, we propose a data processing pipeline that allows automatic inspection and monitoring of underwater structures using 2.5D and 3D data provided by either acoustic or optical sensors.

**Keywords** – Underwater inspection, 3D/2.5D data processing, multimodal information, change detection.

## 1. INTRODUCTION

In the recent years, an increased attention has been given to the underwater environment as an alternative source of natural and food resources, ecological/biological/geological monitoring, etc. On the other hand, multiple industry sectors, from oil extraction to power and telecommunications use underwater structures that need constant monitoring and maintenance.

Despite all this, most of the underwater inspection and monitoring is still done manually, using divers, limiting the range and depth of the related activities and exposing the personnel to inherent risks.

In this paper we describe a complete processing pipeline that enables automatic inspection and monitoring of underwater structures. The pipeline uses 2.5D and 3D data acquired by acoustic and optical sensors mounted on ships or underwater vehicles, such as Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs).

The work described here has been developed in the context of the PICMAR project. The main objective of PICMAR (Intelligent Platform for the Multimodal Characterization of Seafloor and Underwater Infrastructures), founded by the Ministry of Science and Innovation, is to overcome the limitations of current systems to perform the inspection and management of seafloor and underwater infrastructures.

To achieve this goal, the combination of multimodal information, coming from optical and acoustic sensors, namely high-resolution video camera, side-scan sonar and multi-beam sonar, is proposed. The data acquired by each of the sensors is used to generate 2D and 3D representations of the seafloor, which can be later studied by the scientists. Additionally, this information is acquired and registered on a common georeferenced frame, allowing the association of the data coming from different sensors,

in order to improve the accuracy in tasks such as seafloor classification or change detection.

## 2. UNDERWATER 3D MAPPING

The 3D modeling of underwater structures can be obtained by means of acoustic and optical sensors. Acoustic-based 3D modeling generally involves the use of multi-beam sonars that use time-of-flight principles to obtain range information. This information, along with other data, (such as positioning and attitude) is used to generate 2.5D maps of the surveyed area.

The challenge is to obtain 3D information using optical sensors, which do not directly provide 3D/range clues. In this case, the 3D information is recovered from the scene parallax. The optical data is acquired by multiple calibrated cameras or by a single, moving camera. The use of a single camera allows greater acquisition flexibility and reduced costs, with a slight decrease in accuracy. For this, we propose the use of a method entitled Direct Structure from Motion (DSFM) [Nicosevici et al. 2013]. DSFM can cope with the common challenges found in the underwater environment, such as: occlusions, motion blur, moving objects, lighting changes, low image contrast, etc. Another important advantage of DSFM is the direct computation of camera position, which highly reduces the errors in the resulting 3D map. Figure 1 illustrates an example of a 3D map obtained using DSFM.

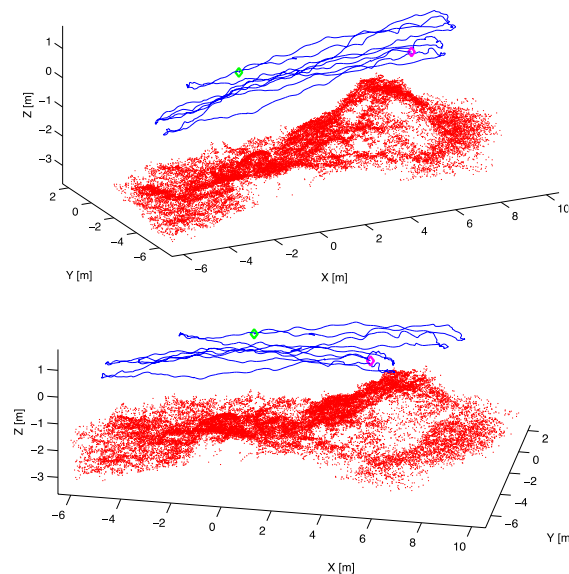


Figure 1. 3D reconstruction of an underwater scene along with the estimate camera trajectory, obtained using DSFM.

### 3. DATA FILTERING

The data-filtering step allows removal of mapping artifacts, such as outliers generated during the mapping, and the filtering of the 2.5D/3D maps. Yang et al. [Yang2012] proposed a method for data filtering using a smoothing approach. While this technique is effective in reducing the noise in data, it generally results in the loss of detail [Kazhdan2006]. In order to address this shortcoming, we propose the use of a k-means clustering techniques, which allows grouping 3D points corresponding individual objects or surfaces. In this way we can remove 3D points that do not correspond to any objects/surfaces in the scene.

### 4. CHANGE DETECTION

One of the main advantages of the pipeline presented here is that it also enables temporal monitoring of underwater structures. For this reason, multiple surveys of the same area or structure are carried out at different points in time. The system will then automatically detect geometric differences that correspond to structural changes.

The process is carried out in two stages: (i) accurately register the 2.5D/3D maps corresponding to different surveys and (ii) detection of structural differences between the maps. The registration process involves an initial, rough registration by means of georeferencing information. This initial registration is then refined using techniques based on Iterative Closest Point (ICP) [Besl et al. 1992, Zhang 1994]. We propose the use of ICP by means of two different approaches, depending on the structure of the scene: point-to-point association and point-to-plane association.

Once the maps have been processed and registered, the final stage is the change detection. The changes are quantified by means of the volumetric differences between the 2.5D/3D maps. In order to calculate the volumetric differences, in the PICMAR project we have developed a technique based on the Hausdorff distance [Ebrahimi et al. 2002]. This technique involves the computation of the metric distance between each 3D point in one of the maps and the closest 3D point in the other map. This strategy allows us to generate a reciprocal model of the differences between the maps, resulting in a robust change detection process. In the case of complex maps, containing millions of 3D points, the associated computational cost is reduced by using Fast Approximate Nearest Neighbor strategies [Muja et al. 2009].

Figure 2 shows the result of the change detection process with prior data filtering. Small volumetric differences due to acquisition and processing noise can lead to false positives in the change detection process. Figure 3 illustrates the result when data filtering is used – in this case, the noise is highly reduced, leading to more robust change detection.

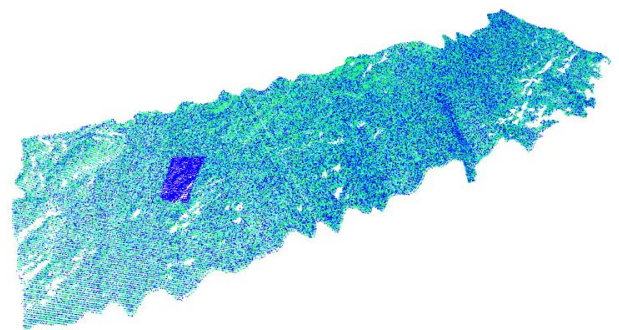
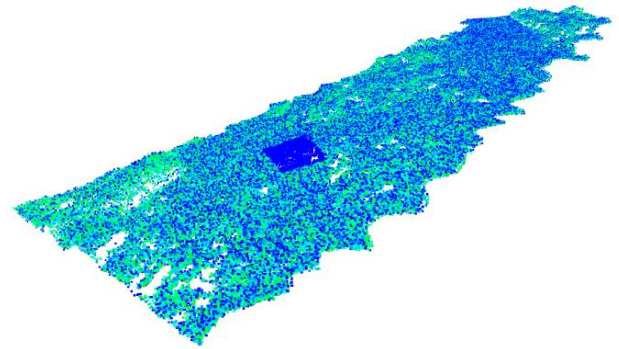


Figure 2. Visual representation of the volumetric differences between 2 explorations, without data filtering (green corresponds to small differences while blue corresponds to large differences). The noise in the data can lead to false positives in the change detection process.

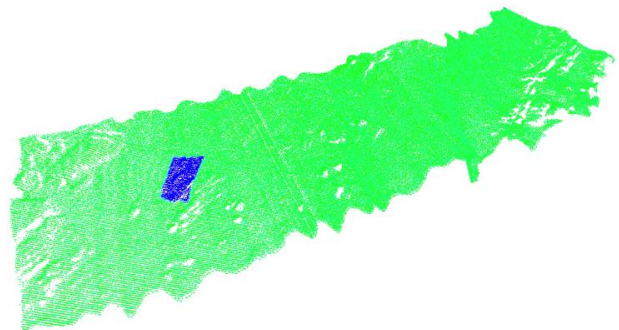
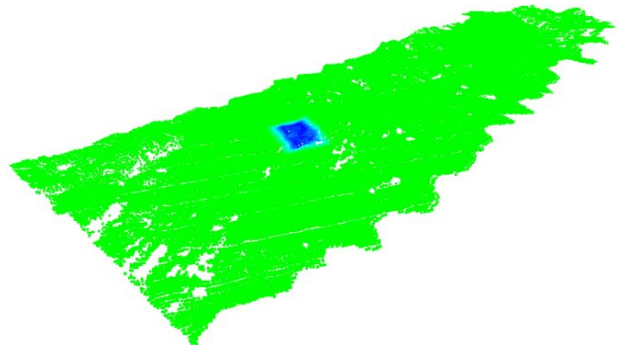


Figure 3. Visual representation of the volumetric differences between 2 explorations with data filtering. The use of data filtering strategies clearly increases the accuracy of the change detection process. The region corresponding to the real change is shown in blue.

## ACKNOWLEDGEMENTS

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