

## Underwater Photogrammetry and 3D Reconstruction of Submerged Objects in Shallow Environments by ROV and Underwater GPS

**Jonathan Teague\* and Thomas B. Scott**

Interface Analysis Centre (IAC), HH Wills Physics Laboratory, Tyndall Ave, Bristol BS8 1TL

**\*Corresponding author:** Jonathan Teague, Interface Analysis Centre (IAC), HH Wills Physics Laboratory, Tyndall Ave, Bristol BS8 1TL, E-mail: jt16874@bristol.ac.uk

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Dr. Carlo Beltrame and Dr. Muhammet Turkoglu

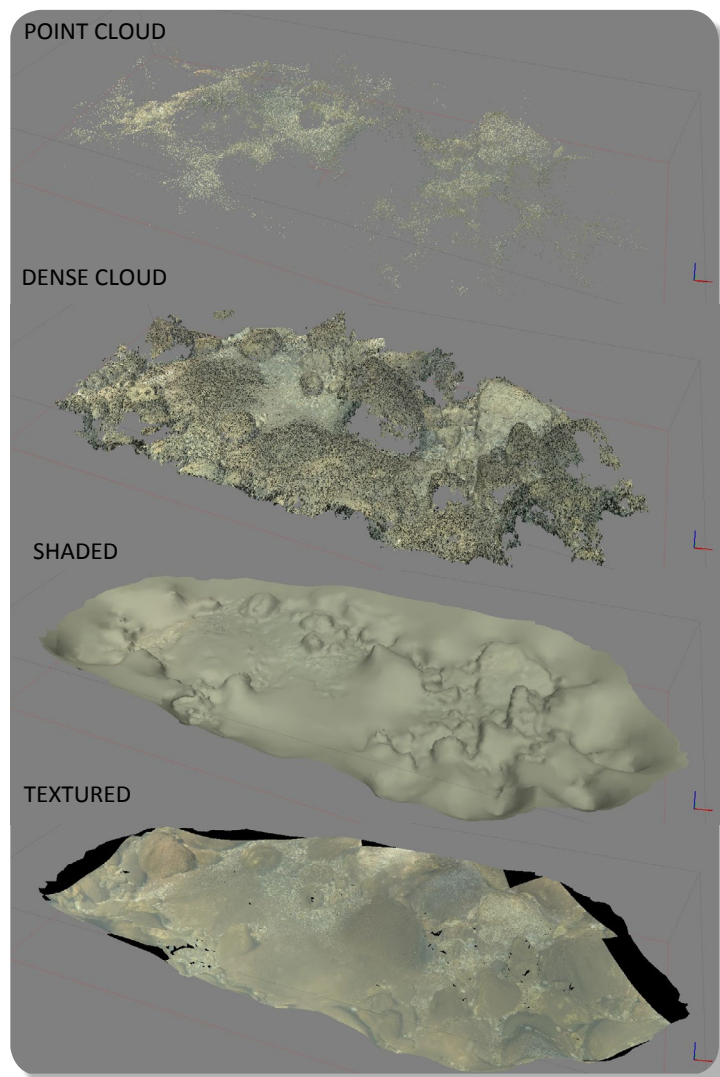
### Abstract

Underwater 3D reconstruction techniques such as underwater photogrammetry are the latest trend in low cost survey techniques. Allowing for high resolution models to be fabricated using off-the-shelf digital cameras and editing software, this method in shallow water environments provide a welcome alternative to costly methods such as Lidar & Sonar. We discuss the method of using current low cost ROV's as platforms forming the basis of underwater photogrammetry surveyance, providing speed and stability over the traditional use of divers. New technologies now available in the low cost market give the abilities for underwater vehicles to be tracked and positioned in real time using acoustic transponders in a network with known surface GPS. Such advances will enable photogrammetric models to be georeferenced which is of great aid to areas of research not limited to archaeological heritage and coral reefs studies.

**Keywords:** Underwater Photogrammetry, ROV, Underwater GPS

## Introduction

Monitoring of the marine environment is an ever-evolving landscape of methods and techniques, from the high-tech of Lidar & Sonar to the seemingly low tech of standard cameras. Scientists are finding new ways to quantify and record data on areas of the oceans, be it archaeological, biological, chemical or physical. Underwater 3D reconstruction techniques such as Photogrammetry are among the latest of these advancements, which has primarily been utilized for seafloor habitat characterization, bathymetry mapping, marine environment inspections and archaeological surveys (Figure 1) [1-5]. Several recent studies used off-the-shelf Structure-from-Motion (SfM) photogrammetry software to build 3D models of reefs and characterize the quality of these reconstructions [5-8] establishing confidence in the use of visual reconstructions to address ecological questions [5,9].



**Figure 1.** The photogrammetry processing steps in order: (1) point cloud, (2) dense cloud, (3) shaded and finally (4) textured. Model map of 149 images, 38,858 data points.

## Photogrammetry

It can be defined as “the use of photography in surveying and mapping to ascertain measurements between objects”. By taking photographs from at least two different locations, so-called “lines of sight” can be developed from each camera to reference points on the model. These lines of sight are mathematically intersected to produce the 3-dimensional coordinates of the points of interest [10]. This method has been used to map areas most commonly by aeroplanes, more recently UAVs have been used to map areas such as minefields for mine detection [11]. This method has started to be utilised in the underwater world. The main advantage of using photogrammetry in underwater surveys in comparison of existing techniques is its simplicity (equipment, method) and the diversity of types of results achievable (accurate 3D measurements of objects, 3D reconstruction of surveyed areas, orthophotography, and vector restitution) [12]. The principle of underwater photogrammetry is the same as that of terrestrial or aerial photogrammetry, but there are factors that need to account for certain disturbances, the refraction of the dioptré water-glass and the presence of the housing [13]. The challenges of the underwater environment include the turbidity of water and the presence of suspended particles. This means operators work on large scales, much closer to objects (between 0.5 and 2 to 3 meters, depending on the water quality) [12].

The developments and recent advances in sensor technologies and computer vision have enabled three-dimensional reconstructions of bathymetry from which benthic categories [14-16] and multiscale structural complexity [17] can be estimated. New data processing capabilities have led to relatively inexpensive commercially available off-the-shelf digital underwater cameras and photogrammetry software that can run on a powerful but ordinary PC. [18]. Such software includes Agisoft PhotoScan which is photogrammetric processing software of digital images and generates 3D spatial data [19].

The use of SfM photogrammetry, which is an emerging low-cost simpler, faster photogrammetric method for high-resolution 3D topographic reconstruction [4,20]. SfM produces digital elevation models (DEMs) that can

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be analyzed using topographic software tools such as ArcGIS. This process enables structural metrics to be quantified such as surface complexity (3D/2D surface area), slope, and curvature [5]. Studies [20,21] indicate the principle advantage of SfM is the geometry of the surveyed area, the varying camera positions, and orientations are evaluated without the need for georeferenced targets especially as GPS does not work underwater.

These techniques rely on combining overlapping images into a composite 3D reconstruction, and while they can scale vast areas consisting of tens of thousands of images, they need a systematic way of covering the survey site. These photos are processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view). These photos are also used in automated processing for Digital Elevation Model (DEM) creation [22]. Poor coverage in the form of gaps or holes (missing imagery) or in low overlaps (low number of views of the same scene point, resulting in low-precision triangulations and structure estimates) compromise the usefulness of the imagery. A good level of overlap is considered to be approximately 80% between on-lapping (overlapping images in the direction of flight) images and 60 - 80% between side-lapping (overlapping images perpendicular to the direction of flight) images [23]. To quantify spatial properties of the configuration, conformation, contour, form, and shape of the coral reef environment, the DEM of the surveyed area can be exported from the Agisoft Photoscan into ArcGIS. 3D characteristics of the reef including all parameters can be quantified using spatial analysis tools in the ArcGIS program [5].

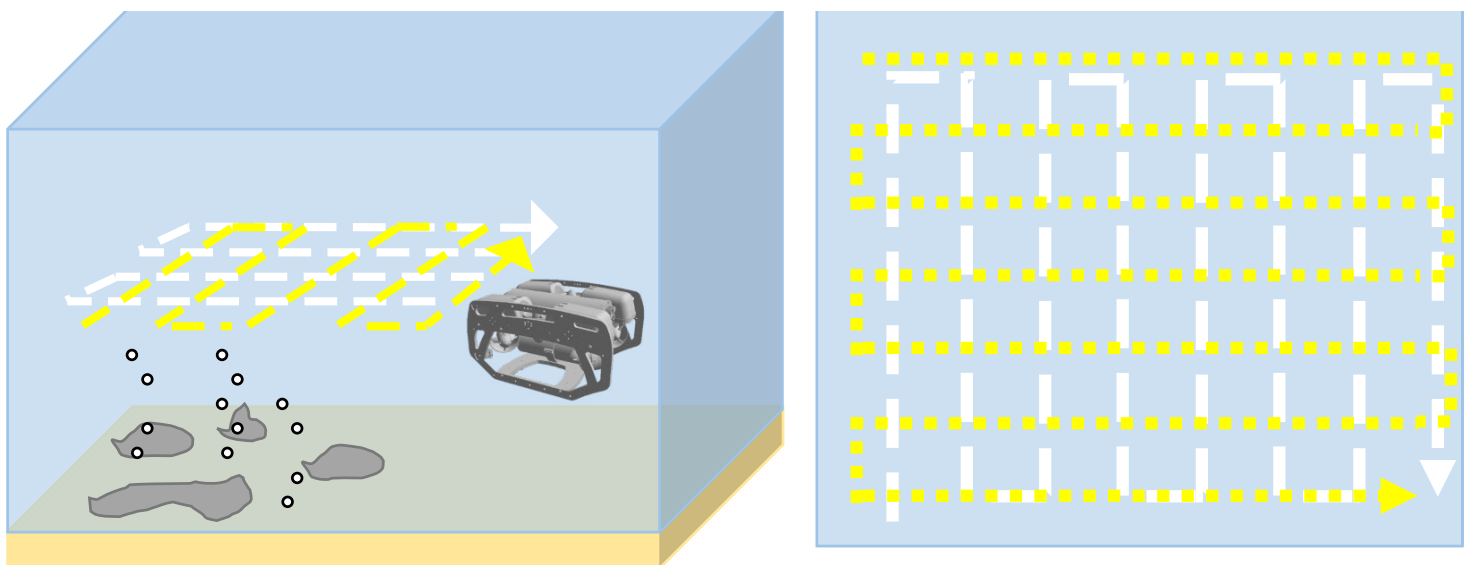
The ROV photogrammetric survey of the seafloor is

achieved by 'flying' in two intersecting raster patterns. The attached HD camera took visual data in the form of either a video or time-lapse, a similar approach to establish unmanned aerial vehicle (UAV) photogrammetry techniques, allowing for sufficient overlap of images between transects. Once data is obtained images are added to Agisoft Photoscan in order to make 3-dimensional models, the program uses the process of structure from motion (SfM) photogrammetry.

## Divers vs ROV

Recent years have seen advances within underwater robotics, creating a wave of low cost systems able to affordably provide an alternative to divers, reducing dependency and the constraints associated with them. ROV technologies have been used to map areas of underwater cultural heritage such as shipwreck materials and underwater structures using photogrammetry. McCarthy & Benjamin [4] have shown how a diver-based photogrammetric approach can significantly improve the efficiency of the process of recording underwater cultural heritage. However, by taking the diver out of the equation by using a Remotely Operated Vehicle (ROV) as a platform for data capture removes two very limiting operational constraints (depth and bottom time) [18]. This implementation of this method is time efficient and without the need of specific personnel, creating a reduction to expenses in a context where time and costs of intervention are extremely high [12] (Figure 2)..

McCarthy & Benjamin [4] have shown how a diver-based photogrammetric approach can significantly improve the efficiency of the process of recording



**Figure 2.** (A) 3D representation of raster pattern over vent field showing camera field of view. (B) Top down view of raster pattern survey.

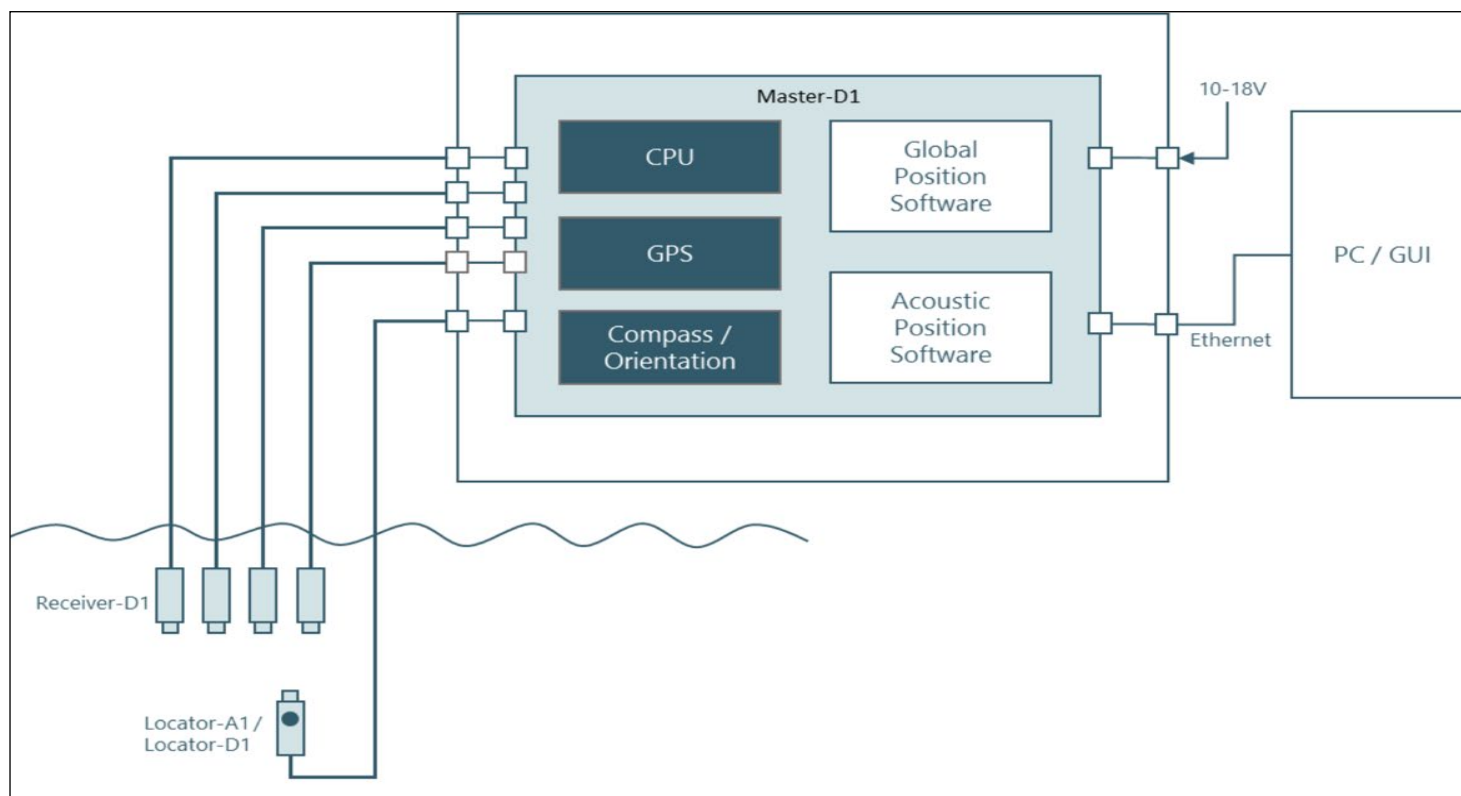
underwater cultural heritage. However, by taking the diver out of the equation, using a Remotely Operated Vehicle (ROV) as a platform for data capture removes two very limiting operational constraints (depth and bottom time) [18]. This method requires less time than a diver and does not require specific personnel, thus greatly reducing the expenses in a context where time and costs of intervention are extremely high [12].

ROV based underwater photogrammetry does not come without its difficulties; low level light will affect the quality of images, currents can take the ROV off course and with no GPS, models cannot be georeferenced without known marker points. However, with the ever-advancing technology of underwater acoustic positioning systems, it is becoming possible to position ROVs underwater and most importantly with advances in transducer technologies and cost decreasing these technologies is now much more affordable. With new technologies as cheap as \$4,000 [24] as a pose to the standard commercial systems being (\$20,000+). These positioning systems are nothing new, with origins to the US navy in the early 1960s [25] but have always been out of reach of industries outside oil & gas. These systems however are still the best solutions for deep water surveys and often the deeper the depth the more cost associated with the acoustic transponder technology.

## Underwater Positioning

One method of underwater positioning is Short baseline (SBL) system which offers a mobile low cost solution as SBL systems do not require any seafloor mounted transponders and therefore suitable for tracking underwater ROV from mobile platforms such as boats or ships that are either stationary or moving (Figure 3). SBL works by connecting three or more individual sonar transducers by wire to a central control box, these send out pings to the object being tracked. By working out speed of transition & angle, the Master board calculates the position of any Locator relative to the position of the Receivers. Combined with the integrated GPS and IMU, it provides an accurate GPS position of the Locator attached to the ROV [24]. The accuracy of the transducer depends on the relative spacing and the method in which the device is mounted, accuracy is proportionate to the greater the distance between transducers (greater distance, greater accuracy) [26].

These systems could be implemented alongside low-cost ROV to produce a versatile platform for underwater photogrammetric surveys establishing models of the environment which already have an accuracy of 2mm or higher. Studies comparing 3D modelling accuracy against conventional methods (foil wrapping) [27] for coral surface area calculates the mean percent error

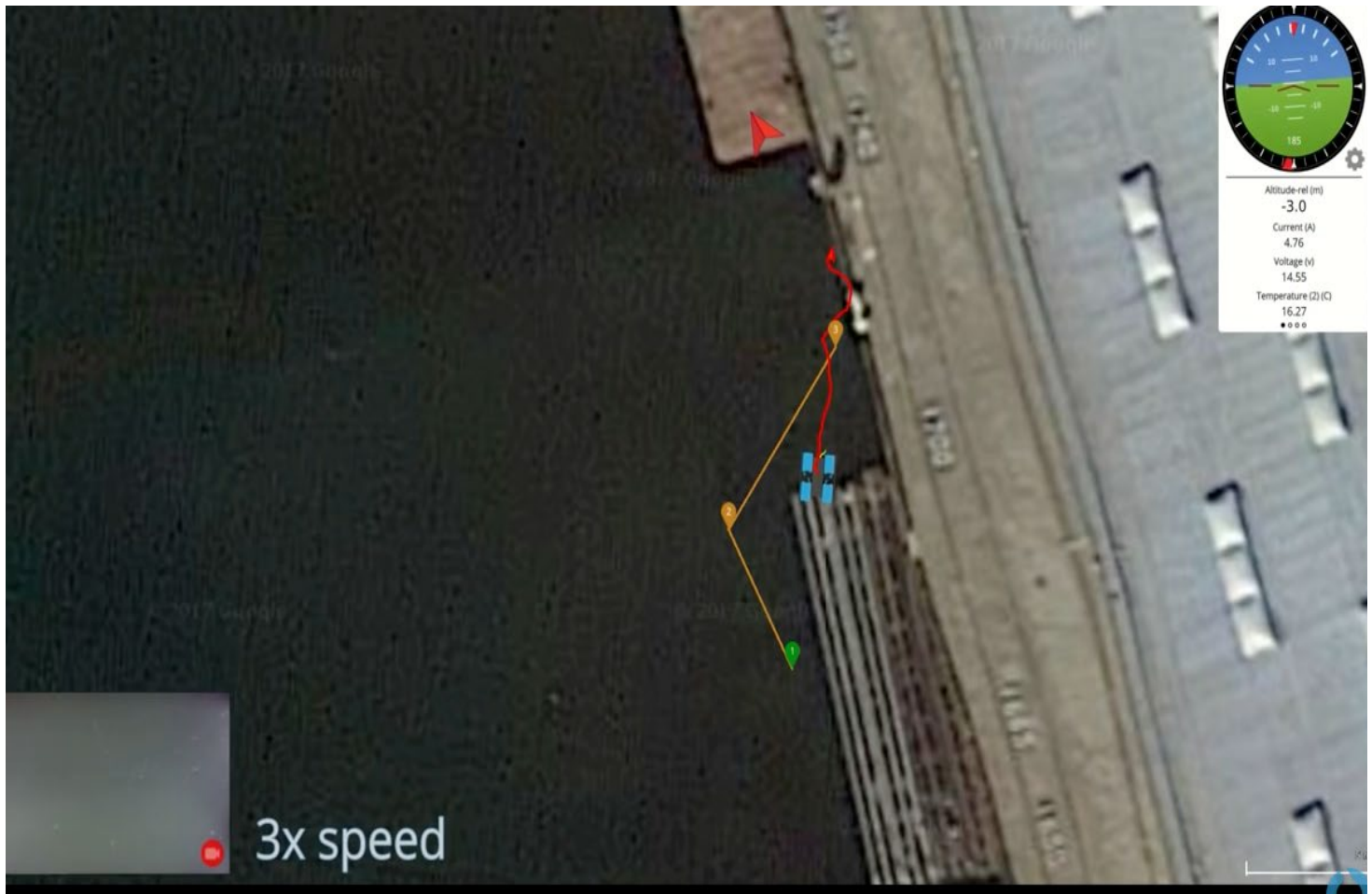


**Figure 3.** Waterlinked underwater GPS schematic [24].

between the two was  $\pm 0.21\%$ , with a standard deviation of  $0.47\%$ . [28]. These SBL systems will allow for data to be georeferenced and submerged objects to be accurately GPS coordinated. This enables processing software such as Agisoft to quicker align images, because it knows where each image is and scale the final model. With the advances in this technology ROVs can be used in a similar way to UAVs with planned missions (waypoints), enabling photogrammetry surveys to be operated with more accuracy and allowing flight paths of the ROV to be recorded. (Figure 4)

Combining the two low cost methods of SfM photogrammetry and SBL positioning create a powerful

new technique for monitoring and surveying the marine environment cost effectively. For shallow water environments the use of SfM & SBL will enable high resolution models with a low budget. Even without the use of SBL positioning high resolution images can be produced using low cost ROV and a standard waterproof camera, without the need for specialised personnel and on low budgets of less than \$1500. This opens up a powerful tool to the marine scientist's arsenal and will enable countless surveys to be performed within the photic zone.



**Figure 4.** Screenshot of Blue ROV2 automated waypoint mission using Waterlinked Short baseline (SBL) system [29].

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