Underwater Photogrammetry for Change Detection

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SUMMARY

Underwater surveying has been used for several applications in oil industry, archaeology and biology. The presentation will focus the attention on underwater photogrammetric surveying for change detection applications. Structure from Motion photogrammetry and underwater imagery allow the three-dimensional quantification of submersed structures characteristic at patch scale and structural complexity. High accuracy and resolution are required in order to guarantee the repeatability of surveys over time within the same reference system; a proper geodetic network and acquisition scheme are mandatory as well for 3D models generation.
The direct comparison of multi-temporal point clouds enables the evaluation of the main trends and modification with an accuracy of millimeters to centimeters accuracy.
Some examples of underwater photogrammetry for change detection will be shown and particularly with reference to a case study of multi-temporal underwater photogrammetric survey of a reef patch located in Moorea Island to detect a coral growth of about 10 mm\years.

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Underwater photogrammetric surveying through images acquired by divers and unmanned underwater vehicle has been used for many applications in oil industry, archaeology and biology for change detection purposes at high accuracy level (less than 1 cm accuracy) depending on the camera settings used and the distance to the imaged object (Capra 1993, Capra et al. 2015 and 2017; Drap et al. 2013; Sarakinou 2016; Shortis 2015 and 2019).

Particularly useful for these activities has been the utilization of Structure-from-Motion (SfM) photogrammetry (Agüera-Vega et al. 2016; Eltner et al. 2016; Fonstad et al. 2013; Harwin et al. 2015; Mancini et al. 2013; Nex and Remondino 2014; Rupnik et al. 2014 among others). The absolute positioning of the 3D models is achievable at high accuracy level when a reliable reference frame is established using ground control points (GCPs) whose coordinates have been surveyed and determined with standard deviations ranging from several millimeters up to 1 cm. Information about the accuracy achieved by the underwater photogrammetric surveys is essential whenever these data are planned for deformation monitoring playing a crucial role to determine the rate of changes from multi-temporal underwater photogrammetric surveys.

The case study used for describing the strategy for a reliable underwater surveying for change detection purposes refers to a multi-temporal photogrammetric survey of a patch reef located in Moorea, French Polynesia. The main aim of the project is to provide a workflow for the 3D mapping and monitoring of coral reefs at the level of accuracy required to detect annual changes in the 3D structure of the reef .

The applied **methodology** lies in geodetic and photogrammetric measurements, data processing and multi-temporal analysis and is deeply described in Rossi et al., 2019; a short summary of the case study is here reported.

In the monitoring of growth or loss of coral 3D structure at millimeters to centimeters level of accuracy, an accurate geodetic network has been established to guarantee a common unambiguous reference frame for further comparison of the photogrammetric models reconstructed from underwater photographic surveying over time (Guo et al. 2016; Rossi et al. 2019).

In the mentioned case study, the **geodetic reference frame** was established by installing and surveying a high-quality underwater control network, which is composed of benchmarks in fixed positions; highly redundant collection of distance measurements and highly accurate leveling with laser points have been carried out. The local network adjustment produced GCP coordinates at sub-centimeter level of accuracy that were used as reference markers in the external orientation of photogrammetric models.

Several models of cameras either singly or in multiple camera combinations were used to acquire imagery in order to test camera performance in the underwater environment and identify optimized camera settings (Guo et al, 2015,Nocerino et al, 2019, Rossi et al., 2019). A Lumix DMC-GH4 and a Nauticam underwater housing equipped with a dome port to reduce the distortion effects generated by the aquatic medium (Menna et al. 2016) was used as the standard reference camera, with a nominal focal length as fixed in air of 20 mm in 2017 and 22 mm in 2018 and an exposure time of 1/90 s during 2017 survey and 1/125 s in 2018 survey in order to optimize image capture and reduce motion blur.

Rossi et al. 2019 provides the detailed description of the **photogrammetric processing for 3D models** generation (SfM algorithms by means of Agisoft Photoscan software suite) whose main steps are here listed: removal of all poor quality images (i.e., out of focus, motion blurred) from the processed dataset; image orientation with bundle adjustment; GCPs coded targets automatically identified in the images; refinement orientation through a non-linear, least squares minimization during the bundle adjustment; self-calibration procedure; depth map and creation of a high-density point cloud; validation of the generated point clouds and the estimation of their final accuracies (Toschi et al. 2013).

A **multi-temporal analysis** was performed by the comparison of 3D models obtained in two subsequent years to detect any significant changes in reef geometry over time by calculating the oriented distances between the two 3D models using the M3C2 algorithm (Lague et al. 2013; Rossi et al.,2019). The comparison procedure was accurate enough to precisely detect typical rates of changes occurring in the structural properties of corals on the order of 1 cm/year (Bessat and Buigues 2001; Burns et al., 2015; Skarlatos et al. 2017; Neyer et al. 2018); therefore the case study achieved the goal to detect a coral growth of less than 10 mm\years and it could be followed as general methodology for the high accuracy change detection purpose.

The use of the same GCP coordinates each year, the minimal constraint reference network, similar flight paths, together with the repetition of subsequent surveys under similar environmental conditions (summer months), are all strategies allowing managers to remove errors related to instrumentations, observers, sea currents, refraction indices, and seasonal variations.

The proposed, underwater photogrammetric methodology allows for a cost-effective approach to the quantitative assessment of a complex structure change with an estimated **accuracy of about 10 mm/year.**

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