5th Joint International Symposium on Deformation Monitoring (JISDM), 20-22 June 2022, Valencia, Spain
DOI: http://doi.org/10.4995/JISDM2022.2022.13891

Monitoring of underwater animal forests: geometry and biometry

Paolo Rossi[1], Cristina Castagnetti[1], Stefano Cattini[1], Giorgio Di Loro[1], Francesca Grassi[1], Luigi Parente[1], Sara Righi[1, 2], Luigi Rovati[1], Roberto Simonini[2], Alessandro Capra[1]

[1] Engineering Department "Enzo Ferrari", University of Modena and Reggio Emilia, 41121 Modena MO, Italy, (paolo.rossi@unimore.it; cristina.castagnetti@unimore.it; stefano.cattini@unimore.it; giorgio.diloro@unimore.it; francesca.grassi94@unimore.it; luigi.parente@unimore.it; sara.righi@unimore.it; luigi.rovati@unimore.it; alessandro.capra@unimore.it)
[2] Life Sciences Department, University of Modena and Reggio Emilia, 41121 Modena MO, Italy, (roberto.simonini@unimore.it)

Key words: *high resolution; UW animal forest; deformation monitoring; photogrammetry; fluorescence; ROV*

ABSTRACT

The development and testing of innovative technologies and automated data analysis methodologies offer tools for investigations in numerous scenarios including the monitoring of complex marine ecosystems and the direct and indirect effects of climate change on natural heritage. In the underwater environment, the creation of products with accurate metric and colorimetric content is a scientific and technological challenge, that can offer tools for new investigations including the monitoring of ecosystems and the study of biodiversity. The research group developed a technological solution consisting of a remotely operating platform and a measuring system that includes RGB and fluorescence optical sensors for the 3D reconstruction of the underwater environment and the study of the health-state of investigated species. The proposed solution aspires to high-accuracy multiscale reconstruction of underwater animal forests with a special focus on metric content. Methodologies and technical solutions for the management and calibration of the system have been developed: the design of proper calibration frames and the fluorescence sensor, the choice of a proper illumination system, the implementation of the system on a customizable Remotely Operating Vehicle, the integration of the different sensors, the combination of metric and colorimetric results for monitoring the occurred deformations and the health status. The results of laboratory activities and preliminary tests on field tests are discussed.

I. INTRODUCTION

The creation of 3D products with accurate metric and colorimetric content for the reconstruction of the underwater environment represents a scientific and technological challenge that may offer new tools for investigations in numerous contexts, including the study of biodiversity and the monitoring of ecosystems such as the marine animal forests (Rossi *et al*., 2020).

Animal forests are seabed communities dominated by sessile filter feeders, including sponges, bivalves, gorgonians, and corals. They have a high naturalistic and tourist-cultural value hosting a wide range of species and creating complex and spectacular underwater landscapes (Rossi *et al*., 2017). These ecosystems are threatened by climatic and anthropogenic pressures acting on local and global scales (Guarnieri *et al*., 2016). Among the species at risk, the scleractinian *Cladocora caespitosa* (the only endemic bioconstructor coral in the Mediterranean Sea) and the gorgonian *Eunicella singularis* are habitat formers threatened by seawater warming. Thermal anomalies can cause stress and increase mass mortality events, altering the structure of animal forests with effects on the entire associated communities (Heron *et al*., 2016; Kersting *et al*., 2013). The study and analysis of habitat formers need the implementation of new observation systems to be mounted on underwater drones or used by divers, and the definition of high-resolution mapping procedures based on new survey methodologies. *C. caespitosa* and *E. singularis* are zooxanthellate species that emit green fluorescence. Thus, their health state could be assessed by analyzing both intensity of fluorescence and natural color and investigating the 3D complexity of their skeleton. This contribution will deal with photogrammetry, which allows a non-invasive investigation capable of returning metric and colorimetric information of the detected object (Drap *et al*., 2015; Storlazzi *et al*., 2016); and fluorescence and reflectance, which are widely used to assess the health of plants and other organisms, but have still not been commonly employed in underwater investigations (Eyal *et al*., 2015).

The traditional photogrammetric technique is based on stereoscopy, although its application for underwater surveys is tricky due to several issues related to the acquisition of images and their processing. Recently, Structure from Motion (SfM) techniques have enhanced photogrammetric 3D reconstruction also in the underwater environment (Figueira *et al*., 2015; Shortis *et al*., 2015). The use of computer vision algorithms allowed a simplification of images acquisition, moving the camera around the object (Lavy

et al., 2015). However, if the purpose of the 3D reconstruction is the measurement of geometric parameters of benthic organisms or the monitoring of deformations over time, it is also necessary to guarantee metric and georeferenced products, that require the installation of targets and ground control points with known coordinates. Some experiments (Burns *et al*., 2017; Raoult *et al*., 2017; Nocerino *et al*., 2020; Rossi *et al*, 2020) have been carried out in submerged environments for the monitoring of the seabed and the health of corals, but the methodology is still little applied and has not been scientifically validated yet.

Within this contribution, the authors show the first stages of the design and development of a measuring system integrating optical sensors capable of acquiring natural color (RGB) and fluorescence images. These instrumentations are useful for the 3D reconstruction of the submerged environment and the state of health of corals and gorgonians. The aim of the research project is the implementation and testing of new methodologies and sensors for monitoring marine ecosystems with high-resolution data over time. Besides, also the evaluation of cost-effectiveness, safety, and repeatability of these environmental observations will be investigated, as the work of divers is often limited and endangered by depth and difficulty of exploration. The general setup and usability of the prototype of sensors were initially assessed at sea by divers and integrated on a submarine Remotely Operating Vehicle (ROV) (after referred to as "on-field test"). Then, its performances were further tested and validated in controlled conditions in an aquarium (after referred to as "laboratory test").

II. Case Study

On-field tests were run on small colonies of the corals *Astroides calycularis* and *C. caespitosa,* and the gorgonian *E. singularis* (Figure 1). Organisms were collected by SCUBA diving at San Vito Lo Capo (Trapani, Southern Tyrrhenian Sea, Italy) among those accidentally detached from the seabed during fishing operations or storms. The on-field measuring site was created attaching the base of corals and gorgonians on metal nets with an epoxy resin (TUNZE Coral Gum Instant). Then, the nets were fixed on bricks, which allowed to raise the target organisms from the bottom and constituted a 3D well-defined measuring site. At the end of the on-field tests, the organisms were transferred to the aquarium for laboratory tests. There, each colony was fixed on stable supports and detected individually.

III. Methods and Materials

A. *Camera and housing*

Both the on-field (seawater) and laboratory acquisitions of RGB images for 3D reconstruction were performed with a CANON 2000D Reflex camera and 18-55 mm EFS lens. The resolution of 24.1 MPixels and the short distances allowed the detection of numerous details of the investigated organisms and the generation of a high-resolution photogrammetric reconstruction. On-field, the turbidity of water suspended materials and the light attenuation given by the water medium confined the acquisition distances to 2 m.

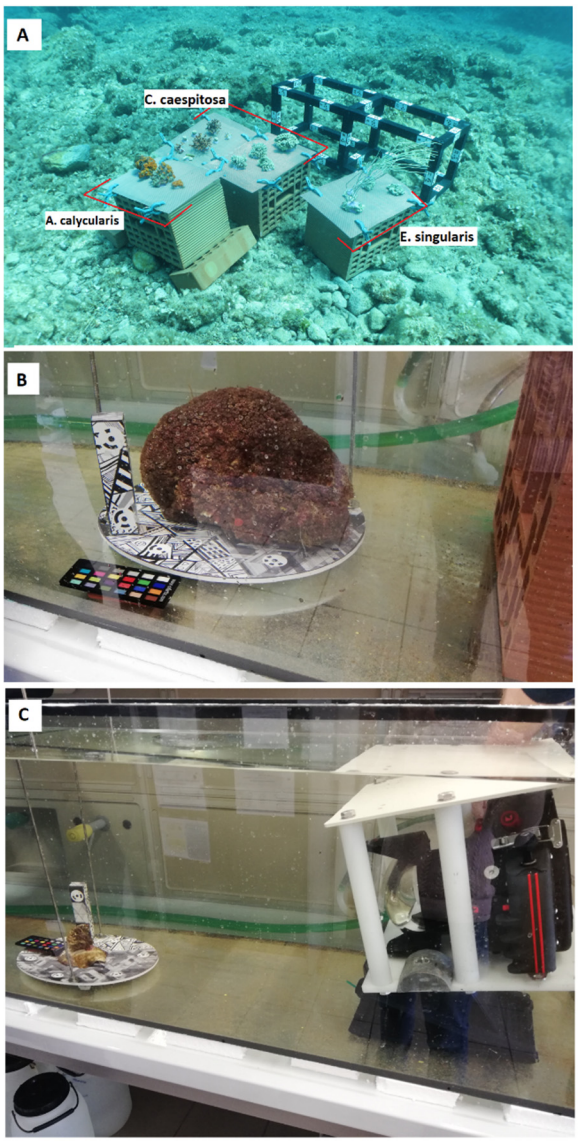

Figure 1. Survey and investigated organisms. A: on-field test site, with corals and gorgonians fixed on nets placed on bricks next to the calibration frame (parallelepipedon). B: laboratory test with the calibration plate, a color checker, and a colony of C. caespitosa. C: overall equipment employed for the photogrammetric survey during laboratory tests: the calibration plate with a coral and the color checker on the left, and the underwater housing with the camera on a support on the right.

The camera was placed in an underwater housing equipped with a dome port (Easy Dive LEO3). This housing was chosen because of its durability and versatility, the electronic transmission of the commands, and the compatibility with several models

and series of cameras. The use of a dome port allowed a reduction of image distortions and the achievement of accurate results in the photogrammetric reconstruction. Indeed, several studies demonstrated that flat ports perform worse than the dome, providing higher image residuals, and lower precision and accuracy in object space (Menna *et al*., 2016; 2017).

B. *Calibration frame*

Photogrammetric processing requires external references to obtain a scaled and accurate 3D reconstruction and the reduction of distortion effects due to errors in images' relative orientation. External references are also defined as Ground Control Points (GCPs) and often consist of targets. In air/terrestrial applications, coordinates of GCPs are generally detected with traditional survey methodologies (*e.g*., GNSS system). In the underwater environment, it is not possible to implement traditional solutions, so the use of fixed points, objects of known dimensions or known distances, is largely adopted (Capra *et al*., 2017; Rossi *et al*., 2020). In this study, two different reference frames were used to constraint photogrammetric reconstruction: in the on-field test, a parallelepipedon (80 cm large, 30 cm height and long made of HDPE material) with 100 targets of known position (see Figure 1A); in laboratory tests, a 30 cm diameter plate with 12 targets printed in known positions (see Figure 1B and 1C). In both cases, a homogeneous and 3D distribution of the targets was employed.

C. *3D reconstruction and deformation monitoring*

Image acquisition was designed to optimize the photogrammetric processing and obtain high-resolution results: high redundancy, different viewing angles, natural light conditions, and automatic focus were set. The acquired images were then processed, together with metric constraints, in the SfM photogrammetry software Agisoft Metashape (v. 1.6.1, www.agisoft.com) that is largely used for activities in the underwater environment (Menna *et al*., 2019; Bayley and Mogg, 2020; Rossi *et al*., 2020; Ventura *et al*., 2022). The processing took the following steps: image alignment (highest settings); targets collimation, integration with reference coordinates, optimization of alignments; dense cloud creation (highest settings, aggressive noise filter); automatic filtering of low accurate points; generation of textured meshes.

The image acquisition geometries were differently designed for on-field and laboratory tests. In particular, the key points consisted of:

- On-field, a time-lapse of 5 s was set up for the automatic acquisition of images. The ROV or the divers followed circular trajectories around the object, maintaining a constant distance of about 1–2 m and changing the angle of view in order to avoid occlusions (Figure 2A).
- In the laboratory, during the acquisition, the camera was mounted over a specific support, while the object was slightly rotated after each shoot (10° to 15°), and the pitching angle of the camera was manually adjusted in order to reduce occlusions and provide a complete reconstruction (Figure 1C, Figures 2B and 2C). Considering the results of on-field tests, a color checker was positioned inside the aquarium as a reference for color variability, allowing to correct the effects of water medium (Bianco *et al*., 2015) and the detection of changes in colony health status (Figures 1B and 1C).

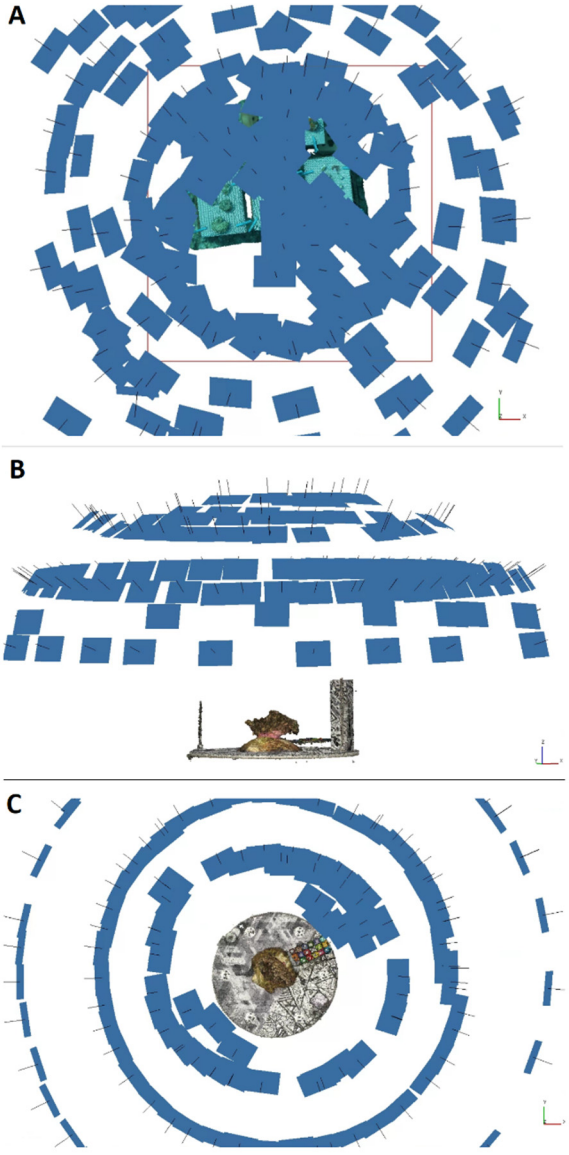

Figure 2. Acquisition of the photogrammetric datasets. A: on-field test, view from the top. B, C: laboratory test, front view, and from the top, respectively.

Generally, the monitoring of geometric deformations (*i.e*., growth of organisms, loss of 3D complexity, portion removal) is carried out through direct comparison of 3D models generated at subsequent epochs. This approach is widespread in numerous

disciplines (cultural heritage, geosciences, infrastructure management, ...), and requires the definition of a reference system unique and stable over time (Valença *et al*., 2012; Abate, 2019; Laporte-Fauret *et al*., 2019). In underwater applications, it is complex to guarantee a unique reference system, and there are few applications to this end (see Nocerino *et al*., 2020; Rossi *et al*., 2020). In this study, on-field activities had the goal of testing the instrumentations and the ROV implementation in real conditions, thus no monitoring activity was planned in this preliminary phase. In the laboratory tests, the 3D reconstruction of the target organisms and the analysis of their geometry aimed at monitoring their health state. The comparison of the resulting point clouds was performed after a co-registration of models based on unchanged portions (the bases on which the organisms were fixed), and then deformations were evaluated.

D. *On-field fluorescence imagery*

In order to observe the fluorescence emitted by healthy specimens of *C. caespitosa* and *E. singularis* in on-field tests, the instrumentation used was the following: a FLIR Blackfly S BFS-PGE-51S5P camera with a TAMRON M23FM16 lens filtered with an emission filter, model FST001 – Alexa 488 (FMF001). The FLIR camera was housed in an acrylic cylinder equipped with a dome port. A white LED-based light source (with CREE XP-E2 LEDs) filtered with an excitation filter, model FST001 – Alexa 488 (FXF001), was applied. The excitation filter applied on the light source allowed to illuminate the organisms with the blue component of the light, that triggers fluorescence. The emission filter applied to the lens of the camera allowed removing the blue light of excitation, letting the green light pass instead (green light both due to the fluorescence and environmental lighting). To separate the signal of interest, that is, the fluorescence generated by the organisms, from the green light component due to ambient lighting, the images were acquired as two frames: a former image, the blank image, in which the excitation light source was switched off (only the ambient light contribution was captured), and, immediately after, a latter image, the fluorescence image, in which the light source was on and both the natural light and fluorescence contributions were captured. To isolate the fluorescence contribution alone, a pixel-by-pixel subtraction was performed between the last frame acquired (light source on, fluorescence image) and the previous one (light source off, blank image), after some pre-processing aimed at re-aligning the two images.

E. *ROV*

The needs outlined in this study led to the search for a ROV easy to handle, highly customizable, and low-cost. The BluROV2 with 8-thrusters configuration (https://bluerobotics.com/), was chosen for the underwater monitoring of corals and gorgonians geometry and health state. The 8-thrusters configuration allows to operate with strong currents; the vertical, lateral, and rotational movements are very effective and fast, and no large maneuvering spaces are required. The software architecture of the system is open and therefore easily customizable. The hardware structure of the ROV is modular and allows the addition of sensors and elements, including expansion kits. At the time of writing, RGB and fluorescence sensors were mounted on the ROV, and both the handling in navigation and the ability to acquire data were tested.

The ROV's full configuration was based on (from top to bottom): a first layer consisting of rotors, electronics, integrated camera, and battery pack; an expansion kit containing the fluorescence sensor and the associated electronics; a polypropylene structure that supports and protect the reflex camera. Several issues have been pointed out in the proposed architecture, and several improvements are planned. These aspects will be deepened in the discussion.

IV. Results

The on-field tests highlighted some weaknesses of the developed systems and their integration on the ROV. Issues in varying the pitching of the ROV without compromising its stability prevented the acquisition of an RGB dataset suitable for photogrammetric processing. The acquired images lacked sufficient redundancy and a complete investigation of the object. Instead, images acquired by the diver gave promising results: an average resolution of the 3D model of about 1 mm, and an overall accuracy on targets of about 1 mm (see Figure 3B). The resolution was sufficient to monitor the individual polyps constituting the colony. Despite the short acquisition distance (1.5 m), the chromatic distortion introduced by the water medium was evident (Figure 1A) since the use of a color checker for color correction had not been considered yet. Moreover, the implemented approach failed in the reconstruction of the thin branches of *E. singularis* (Figure 3B, red polygons).

Tests with the fluorescence camera revealed some critical issues that did not allow the estimation of the fluorescence content. Due to limits in the minimum time distance between the acquisition of blank and fluorescence images that prevented the acquisition of images sufficiently close together in time, the pixel-to-pixel subtraction with the blank image, introduced in the methodologies section, was not effective, since in addition to the pitch angle of the ROV (as described above), also the stability of the vehicle prevented to achieve the result. Figure 3A shows an example of a fluorescence image acquired on-field. The measured values are not representative of the fluorescence emitted by the organism as they are not purged of environmental and reflection contributions.

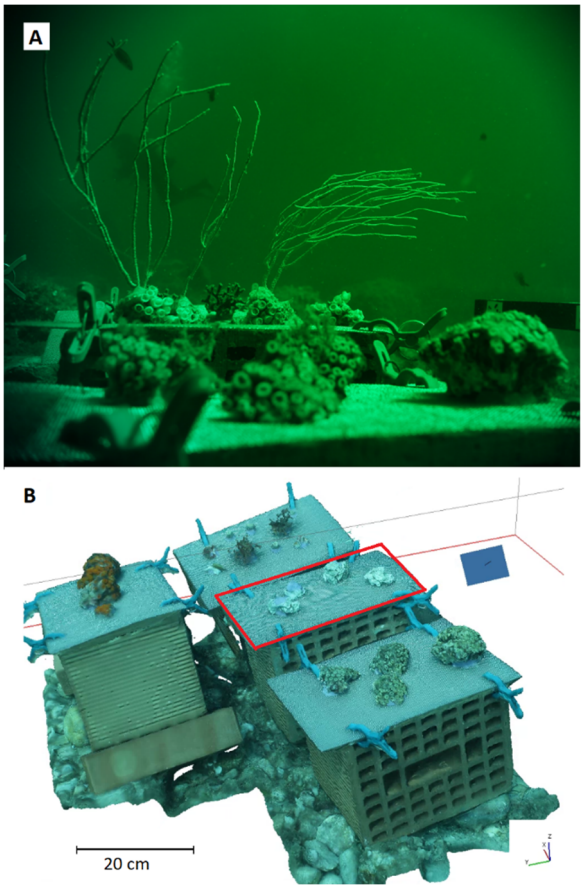

Figure 3. A: example of a fluoresce image acquired during on-field tests. B: view of the 3D model obtained with the images acquired by the diver.

In the laboratory, the acquisitions of the photogrammetric datasets led to the creation of 3D models with a sub-millimeter resolution (0.1 mm) and accuracy on GCPs of the same order (see Figure 4A). The obtained results were suitable to identify single polyps and potentially monitor their changes after exposure to stressful conditions. The color distortion effect generated by the water medium was not appreciable in this case, but the presence of a color checker allowed color calibration and the repeatability of colorimetric analyses.

As regards the monitoring of geometric deformations, the time elapsed did not allow to identify significant changes in the organisms and no artificial stresses were applied. Thus, the repeatability and accuracy of the proposed approach for deformation monitoring were tested by comparing the 3D models obtained for the same organism in immediate succession (from 40 min to 60 min). Figures 4A and 4B shows the areas used for registering the models: the calibration frame, the bases on which the colonies were fixed, and unchanged lower portions. Coregistration provided a mean distance between the unchanged portions of 0.17 mm and a standard deviation (std.dev.) of 0.2 mm (Figure 4C). The "potential geometric deformation" was defined through a comparison of the two 3D models: the mean distance was almost 0 mm with a std.dev of 0.3 mm (Figure 4D).

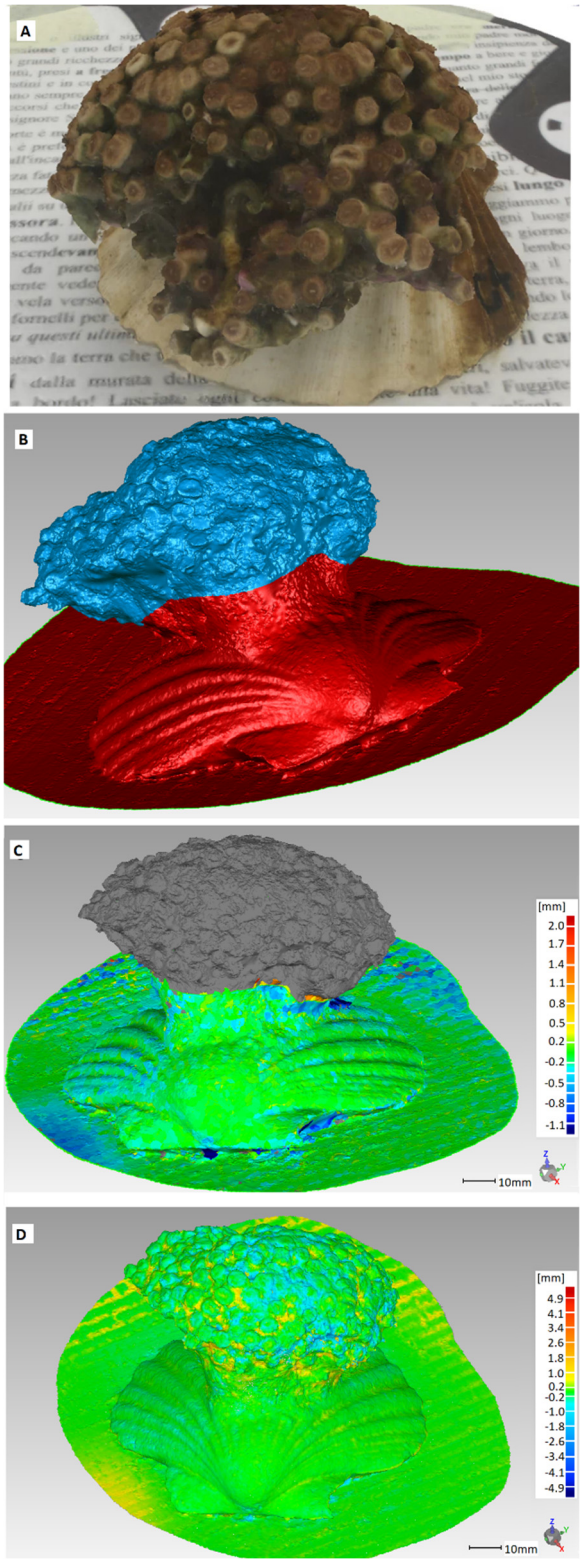

Figure 4. A: 3D model generated during laboratory tests. B: view of the portion used to coregister the subsequent 3D models (red area). C: coregistration results. D: comparison of the subsequent 3D models, detection, and mapping of "potential deformations".

V. Discussions and Conclusions

Laboratory tests led to high-resolution 3D products with sub-millimeter accuracy. Besides, the methodology proposed for the multitemporal comparison of 3D models was promising for

deformation monitoring. No relevant coregistration errors were added, and the detection of a few millimeters deformations was guaranteed. These results were hopeful also in the perspective of future estimations of corals and gorgonians health changes.

The use of a color checker will allow quantitative evaluations of the color variation in the organisms, as a crucial factor to detect the onset of stressful conditions. Authors are considering whether to: apply the same color correction to the entire photogrammetric dataset, correct each image individually, or apply the correction to the texture of the final 3D model. The stability of the camera during the acquisition of fluorescence images had been increased refining the support and acquiring higher-frequency images (2-3 images *per* second) to make the alignment of the fluorescence and blank images more effective, thus allowing an effective compensation of the ambient light. The implementation of the measuring system on a commercial ROV still requires further tests and research. Authors are figuring out: a camera support capable of changing the orientation of the optical axis (from horizontal to nadiral) that could be mounted under the ROV; a raspberry-pie-based system to remotely control the RGB and fluorescence cameras and set the start of the acquisitions and the frame rate, triggering the cameras and illuminators in a sequence suitable for the measurements.

The main goal of the overall project is the implementation and testing of new methodologies and sensors for the monitoring of marine communities providing high-resolution data over time. The preliminary activities described in this paper gave useful information about the potentialities and critical issues of the technologies tested. Methodologies for a high-resolution 3D reconstruction and deformation monitoring are fully operating. Laboratory activities on *C. caespitosa* provided promising results, and similar investigations are ongoing on *E. singularis*. Besides, further data are expected in the short term also for the monitoring of changes in coral health status, since various issues have been resolved. The implementation of the developed measuring system on the ROV still requires numerous tests, hardware and software customization, that are ongoing to face the main emerging issues.

VI. Acknowledgements

Research funded by University of Modena and Reggio Emilia, FAR (Fondi di Ateneo per la Ricerca) 2020.

References

Abate, D. (2019). Built-heritage multi-temporal monitoring through photogrammetry and 2D/3D change detection algorithms. *Studies in Conservation*, 64(7), pp. 423-434.

Bayley, D. T., and Mogg, A. O. (2020). A protocol for the large-scale analysis of reefs using Structure from Motion photogrammetry. *Methods in Ecology and Evolution*, 11(11), pp. 1410-1420.

Bianco, G., Muzzupappa, M., Bruno, F., Garcia, R., and Neumann, L. (2015). A new color correction method for underwater imaging. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40(5), 25.

Burns J.H.R., Delparte D., Gates R.D. and Takabayashi, M. (2015). Integrating structure-from-motion photogrammetry with geospatial software as a novel technique for quantifying 3D ecological characteristics of coral reefs. *PeerJ*, 3, p.e1077.

Capra, A., Castagnetti, C., Dubbini, M., Gruen, A., Guo, T., Mancini, F. T., and Troyer, M. (2017, October). High Accuracy Underwater Photogrammetric Surveying. In *3rd IMEKO International Conference on Metrology for Archeology and Cultural Heritage*.

Drap P., Seinturier J., Hijazi B., Merad D., Boi J.M., Chemisky B., Seguin E., and Long L. (2015). The ROV 3D Project: Deep-sea underwater survey using photogrammetry: Applications for underwater archaeology. *Journal on Computing and Cultural Heritage (JOCCH),* 8(4):1-24.

Eyal G., Wiedenmann J., Grinblat M., D'Angelo C., Kramarsky-Winter E., Treibitz T., Ben-Zvi O., Shaked Y., Smith T.B., Harii S., and Denis V. (2015). Spectral diversity and regulation of coral fluorescence in a mesophotic reef habitat in the Red Sea. *PloS one*, 10(6), p.e0128697.

Figueira W., Ferrari R., Weatherby E., Porter A., Hawes S., and Byrne M. (2015). Accuracy and precision of habitat structural complexity metrics derived from underwater photogrammetry. *Remote Sensing*, 7(12), 16883-16900.

Guarnieri, G., Bevilacqua S., De Leo F., Farella G., Maffia A., Terlizzi A., and Fraschetti, S. (2016). The challenge of planning conservation strategies in threatened seascapes: understanding the role of fine scale assessments of community response to cumulative human pressures. *PloS one*, 11(2), p.e0149253.

Heron S.F., Maynard J.A., Van Hooidonk R., and Eakin, C.M. (2016). Warming trends and bleaching stress of the world's coral reefs 1985–2012. *Scientific reports*, 6, p.38402.

Kersting D.K., Bensoussan N., and Linares, C. (2013). Long-term responses of the endemic reef-builder Cladocora caespitosa to Mediterranean warming. *PLoS One*, 8(8), p.e70820.

Laporte-Fauret, Q., Marieu, V., Castelle, B., Michalet, R., Bujan, S., and Rosebery, D. (2019). Low-cost UAV for high-resolution and large-scale coastal dune change monitoring using photogrammetry. *Journal of Marine Science and Engineering,* 7(3), 63.

Lavy, A., Eyal, G., Neal, B., Keren, R., Loya, Y. and Ilan, M. (2015). A quick, easy and non-intrusive method for underwater volume and surface area evaluation of benthic organisms by 3D computer modelling. *Methods in Ecology and Evolution*, 6(5), pp.521-531.

Menna, F., Nocerino, E., and Remondino, F. (2017). Flat versus hemispherical dome ports in underwater photogrammetry. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 481.

Menna, F., Nocerino, E., Fassi, F., and Remondino, F. (2016). Geometric and optic characterization of a hemispherical dome port for underwater photogrammetry. *Sensors*, 16(1), 48.

Menna, F., Nocerino, E., Nawaf, M. M., Seinturier, J., Torresani, A., Drap, P., and Chemisky, B. (2019, June). Towards real-time underwater photogrammetry for subsea metrology applications. In *OCEANS 2019-Marseille* (pp. 1-10). IEEE.

Nocerino, E., Menna, F., Gruen, A., Troyer, M., Capra, A., Castagnetti, C., .and Holbrook, S. J. (2020). Coral Reef Monitoring by Scuba Divers Using Underwater Photogrammetry and Geodetic Surveying. *Remote Sensing*, 12(18), 3036.

Raoult V., Reid-Anderson S., Ferri A., and Williamson J.E. (2017). How Reliable Is Structure from Motion (SfM) over Time and between Observers? A Case Study Using Coral Reef Bommies. *Remote Sensing*, 9(7), 740.

Rossi S., Bramanti L., Gori A., and Orejas C. (2017). *Marine animal forests. The ecology of benthic biodiversity hotspots*. Cham, Switzerland: Springer International Publishing.

Rossi, P., Castagnetti, C., Capra, A., Brooks, A. J., and Mancini, F. (2020). Detecting change in coral reef 3D structure using underwater photogrammetry: critical issues and performance metrics. *Applied Geomatics*, 12(1), 3-17.

Shortis M. (2015). Calibration techniques for accurate measurements by underwater camera systems. Sensors, 15(12), pp.30810-30826.

Storlazzi C.D., Dartnell P., Hatcher G.A., and Gibbs A.E. (2016). End of the chain? Rugosity and fine-scale bathymetry from existing underwater digital imagery using structure-from-motion (SfM) technology. *Coral Reefs*, 35(3):889-94.

Valença, J., Júlio, E. N. B. S., and Araújo, H. J. (2012). Applications of photogrammetry to structural assessment. *Experimental Techniques*, 36(5), 71-81.

Ventura, D., Mancini, G., Casoli, E., Pace, D. S., Lasinio, G. J., Belluscio, A., and Ardizzone, G. (2022). Seagrass restoration monitoring and shallow-water benthic habitat mapping through a photogrammetry-based protocol. *Journal of Environmental Management*, 304, 114262.