Underwater drones as a low-cost, yet powerful tool for underwater archaeological mapping: Case studies from the Mediterranean

Response to recommender and reviewers

Dear Recommender and Reviewers,

We would like to thank you for taking the time to review our work. Your overall feedback has proven to be constructive and significantly valuable. By carefully addressing each of your comments, we believe that we managed to enhance the quality of our paper. Below you will find the list of the addressed comments (our responses in *italics*), with reference to the updated manuscript's lines. We hope that you will find our revised manuscript worthy of recommendation.

On behalf of all co-authors,
Eleni Diamanti

Recommender

"The paper presents an approach to photogrammetry and drones in archaeology which I consider should be expanded a little bit, perhaps referring to some existent literature as Campana 2017, or Waagen 2019."

- *We have expanded a bit the topic of drones in archaeology referring to (Campana, 2017; Waagen, 2019; Adamopoulos and Rinaudo, 2020) in lines 67-82: "UAV photogrammetry has been widely adopted … sensors like LiDAR (Light Detection and Ranging)".*

"I would suggest to include any critical reference to previous literature dealing with underwater photogrammetry, like Drap 2017, or Yamafune's works (https://sketchfab.com/jenmck13?). Perhaps, the most important question here, is how underwater drones could improve the work done by a single diver."

- *In lines 23-24, we added three characteristic publications (Drap, 2012; Yamafune et al., 2017; Gambin et al., 2023) referring to diver-based photogrammetric recordings of underwater archaeological sites.*
- *In order to elaborate on the question of how drones could improve the work done by a single diver, we expanded the part of the advantages of underwater drones (plus a comparison to human diving) in lines 86-140.*

"I think it will make the experimental section more round, in that line, it would be interesting to create a graph that summarizes the underwater SfM processes."

- *In lines 162-172 we added a flowchart illustrating the three main stages of surveying an underwater cultural heritage site using underwater drones.*

Reviewer #1

“I think the article would greatly benefit from introducing a more detailed workflow scheme (maybe in a figure) in the use of drones in the field at every step of the technique application since we have access to more thorough literature about how the work process of divers for 3D photogrammetry methods are organized it’s still poorly published complete workflow for underwater drones and final products examination.”

- *In lines 162-172 we added a flowchart illustrating the three main stages of surveying an underwater cultural heritage site using underwater drones.*

Reviewer #2

Title

“The paper title suggests a paper with a bit more general information/overview, whereas the main part is a presentation of two case studies. I’d change the paper title a bit to reflect that better."

- *We changed the title to “Underwater Drones as a Low-Cost, yet Powerful Tool for Underwater Archaeological Mapping: Case Studies from the Mediterranean”.*

Structure

“I’d avoid presenting the paper as structured in two sections, where the first section is only 1 page, and the second section is the bulk of the paper.”

- *In lines 6 and 42 we removed the statement that “the paper is divided into two main parts”.*
- *We also expanded the theoretical part of the paper (Section 2) in lines 86-140.*

Content

p.2 >> “Archaeologists were able to survey extended areas in high accuracy and detail, and in a significantly reduced amount of time, with two key advantages: the new technology was affordable and required no scientific or technical background.”

“A bit of nuance; there has also been a wildgrowth of 3D models where the accuracy was not specified, let alone methodological transparency through metadata publication etc. I think “no technical background” is too strong a statement as one certainly needs to understand the basics of photogrammetry/SfM technology for a proper documentation.”

- *In lines 65-67 we edited the text accordingly: “Archaeologists were able to survey extended areas in high accuracy and detail, and in a significantly reduced amount of time, with two key advantages: the new technology was affordable and required only a basic understanding of photogrammetry and SfM principles for effective use.”*

p.7 >> “The first paragraph of 3.1.3 fits better with data acquisition. From this section onwards, the text sometimes reads too much as a technical report covering standard technical/photogrammetrical procedures. I’d leave it out and focus on the analytical aspects of the application.”

- *Indeed, the VSLAM implementation fits better in data acquisition. For this reason, we transferred this paragraph in 3.1.2 section.*
- *We also condensed the first two paragraphs of section 3.1.3 into one (lines 233-239), leaving out technical details that made the text look like a technical report.*

Remainder of the text

"I would also like to see more details in a comparative perspective; both on the ROVs as on the cameras, in terms of costs, performance, etc. There are details here and there, but it would be useful to have them in a table. It could also explain why one was chosen over the other, what choice would be the best etc. In that way, it would be more contributing to the main theme expressed in the paper title."

- *In lines 86-140 we elaborated more on the advantages of the use of underwater drones in the documentation of underwater cultural heritage, with a focus on the comparison with human diving. The suggestion regarding a more thorough comparative analysis on the features of ROVs and cameras in terms of costs and performance is indeed something that we consider for a paper in the near future, once we collect additional data across a wider range of underwater drone models and sensors. This will allow us to make a more in-depth analysis and offer practical recommendations that could be beneficial in the field. The findings of our study are based on the utilization of equipment that was available to us at the time of research, but it's definitely in our plans to conduct such a review soon. Thank you for this comment, it is much appreciated.*

"Maybe also a reflection on expected performance in less optimal contexts? What happens with reduced visibility, waves/currents? What is the effect of moving led light on the photogrammetry? You do say: "A downside of the ROV 3D model was the radiometric inconsistencies that were observed at the texturing and orthophotomosaicking step, mainly due to shadows or overexposed areas occurred by the overlapping lights configuration". But how is the overall photogrammetry process affected (since we know how important consistent lighting conditions are), how about the reprojection error, etc.? I'd like to see some more metainfo on the models produced to be able to estimate their quality."

- *In lines 262-269 we added a few sentences about how the geometric quality of the 3D models was not affected by the inconsistencies in lighting conditions: "Despite the inconsistencies in lighting conditions, the geometric accuracy of the drone-based photogrammetric model was kept high, with the reprojection error remaining sub-pixel after the bundle adjustment. The main parameters that resulted in a low reprojection error were the optimal camera network (bundle adjustment leveraged triangulation from different viewpoints), the redundancy in homologous points within overlapping images (each estimated 3D point was projected in at least 5 images), the existence of calibration data (all cameras were pre-calibrated for the estimation of their intrinsic parameters), as well as the geometric constraints from the navigational data."*