Long Paper

Sonar Mapping and Sampling of Underwater Archaeological Excavations

Case-Study Application at the Oberwartha Reservoir in Saxony, Germany

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Abstract: In this paper, the authors present a system for underwater 3D mapping and excavation by combining a semi-autonomous mini submarine with a radio buoy. The system is designed for archaeological documentation where reliable underwater georeferencing is a major challenge. The buoy provides communication and sensor data to the base station, while the mini submarine carries a ping sonar and videogrammetry equipment for 3D reconstruction. To perform a semi-autonomous dive, a fixed cable length must be selected between the submarine and the buoy, and the dive depth must be set. Therefore, a rough map of available dive depths is crucial to better specify the dive. The authors used a small sonar called Deeper to locate individual measuring points in the water depth and obtain a rough map of the water body. With this information, the authors were able to determine the number and angles of the cameras to be placed on the submarine and adjust the cable length accordingly. The cameras were then used to record the structure of the bottom of the water body and the images were processed using ORB-SLAM3 for real-time 3D reconstruction. The results showed that the system was successful in obtaining 3D maps of the underwater structures and sampling locations. The system was able to provide reliable and accurate depth measurements, allowing the authors to plan the dive in advance and avoid potential difficulties. In addition, the authors found that the system was able to operate effectively in deep water as long as sufficient light was available. Overall, the authors concluded that the semi-autonomous system for underwater 3D mapping and excavation is a promising approach that could be used in other underwater applications. The authors also suggested that future work could focus on improving the accuracy and reliability of the system, as well as integrating additional sensors and algorithms to improve performance.

Keywords: *semi-autonomous UUV—sample collection—orientation with sonar—self-localization*

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1. Motivation and Introduction

For mapping and creating 3D models, as well as when taking samples during underwater archaeological excavations, a prior depth measurement of the water body is a useful and almost essential step (Figure 1) (Block et al., 2018, p. 1).

Fig. 1. Current system with the Buoy above water connected via a yellow cable with the submarine underwater. (© M. Bommhardt-Richter).

Thus, by knowing the documentation area in advance, any difficulties that may arise can be taken care of (Block et al., 2018, p. 2). In addition, before placing the UUV in the water, it is possible to determine how many cameras need to be placed and their angles. The system presented also uses a cable connection between the submarine and the buoy. This can be varied in length in advance. If the maximum depth and the depth difference of the images are known before the dive, the cable length used for the dive can be determined in advance. Since the cameras are used to record the structure of the bottom of the water body, the diving depth is also of decisive importance for the application. Thus, one to three cameras can be connected to the system. Depending on the bottom structure, they may also need to be adjusted in their angle to create a good complete 3D model. Also, on deeper dives, care must be taken to ensure that there is enough light for the cameras. Thus, an additional dive lamp may need to be installed in order to have enough light to take pictures. Now that dive lights, cameras, and cables have been adjusted for the appropriate depth, prior exploration can be used to plan the mission. This is only possible when the cameras are on site, because now the coverage area of the system is known. Following this procedure, the overlap of the individual images can be determined and the paths to be followed can be calculated accordingly. It can also be clarified in advance how a sample can be taken at each location. Possible strategies and options can be determined before the first real dive.

The article is structured as follows: Section 2 provides the theory and related work. In section 3, the application site and the measured data of the sonar are specified in more detail. Finally, a summary with future work is presented in section 4.

2. Theory and related Work

Reliable underwater georeferencing is still one of the biggest challenges in underwater 3D reconstruction. Especially for semi-autonomous control, localization under water is necessary. For documentation in an archaeological context, a system based on the BlueROV II[1] was developed that communicates with the base station via a radio buoy and provides sensor data and receives control data.

[1] https://bluerobotics.com/store/rov/bluerov2/

2.1 Hardware setup and Sonar

The buoy developed in the project can reliably reach distances of up to 500 meters (Bommhardt-Richter et al., 2020). A ping sonar from BlueRobotics[2] was additionally mounted on the submericle. This sonar has an operation range between 0.5 and 70 meters. In this range it can scan the subsoil with a scanning angle of 30° and a scanning speed of 115 kHz. This allows the measurement of the depth between the bottom and the submarine to be measured directly while driving. With the Deeper Pro[3] an additional sonar was inserted at the buoy, which measures the distance from the water surface to the bottom. This allows a rough mapping of the existing water depths and thus better planning before the actual documentation dive. The measurement in the depth allows a range from 0.5 meters up to 80 meters. The scanning can be done either with 90 kHz and a scanning angle of 55° or a faster scanning with 290 kHz and an angle of 15°.

2.2 Videogrammetry, Real-time and Semi-autonomous Mapping

In the field of multicopters, the videogrammetric approach to 3D reconstruction has already been successfully used with different recording strategies (Block et al., 2015) (Figure 2). Underwater videogrammetry has also been shown to be very beneficial in conjunction with automated image enhancement (Block et al., 2017, p. 1) and feature enrichment (Block et al. 2017, p. 2). The use of the video signal for simultaneous localization and mapping during flight for semi-autonomous control is subsequently used for 3D reconstruction with the software “Archaeo3D” (Block et al., 2018, p. 1, Block et al., 2018, p. 2). ORB-SLAM3 is used for real-time 3D reconstruction in the mini-submarine (Campos et al., 2020). To perform a semi-autonomous dive with the goal of 3D reconstruction, a fixed cable length must be selected between the submarine and the buoy. Furthermore, the diving depth (which is currently still fixed) is set. For the hardware setup and the dive, a rough map with the available dive depths is therefore an important tool.

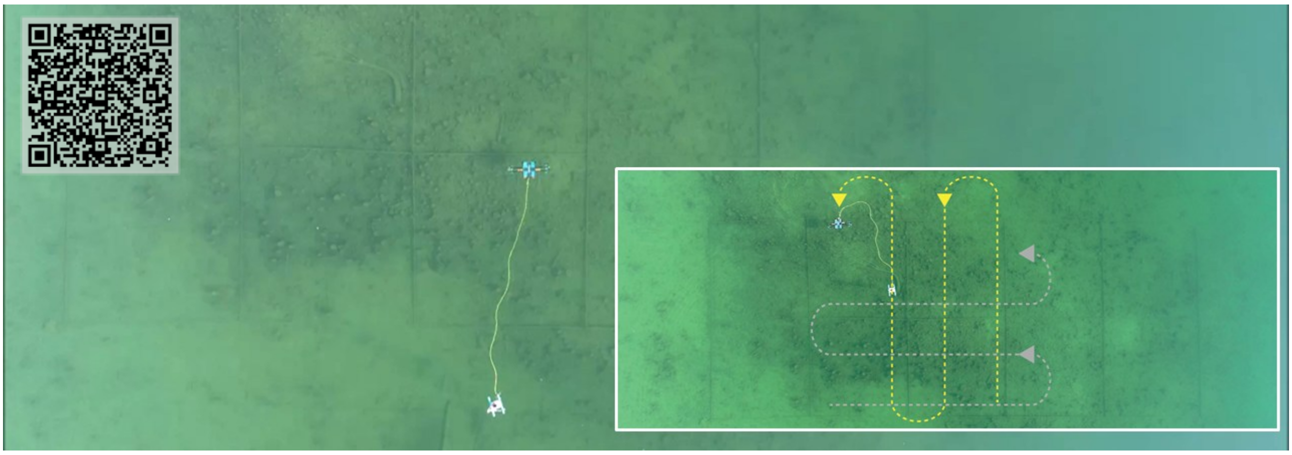

Fig. 2. The recording strategy under water is comparable to that above water. Here, however, the degrees of freedom of the submarine and the cable it carries play an important role in the recording rate. (© M. Block-Berlitz).

[2] https://bluerobotics.com/store/sensors-sonars-cameras/sonar/ping-sonar-r2-rp/

[3] https://deepersonar.com/de/de_de/produkten/deeper-smart-sonar-pro

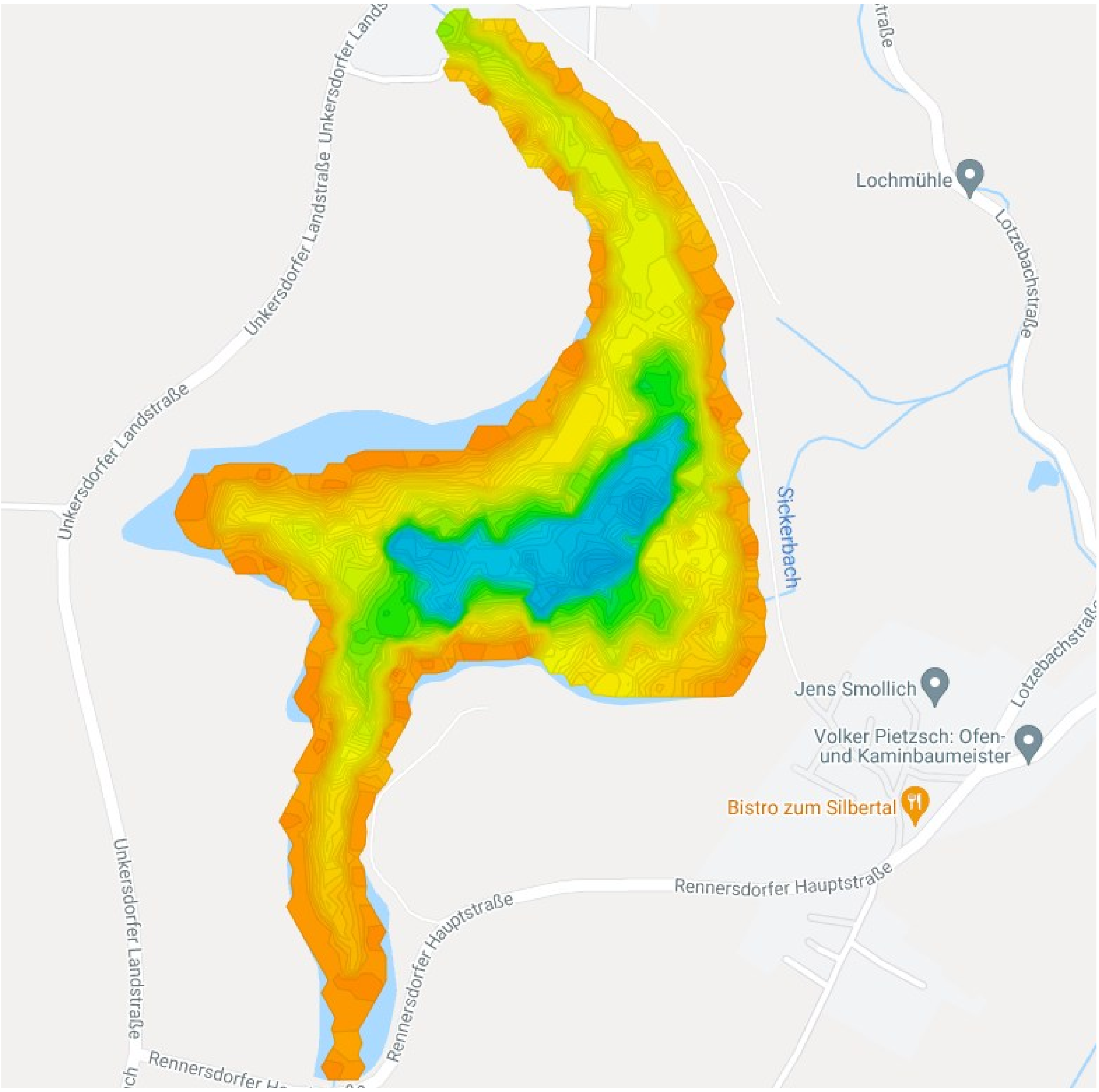

Fig. 3. Here we see the result of the depth measurements: Dark orange up to 1 m, yellow up to 10 m, green up to 20 m and blue up to 20 m. The deepest point of the lake was measured at 29.132 m. (© M. Bommhardt-Richter; Background map Google Maps).

3. Exploration and data collection of the documentation area

As mentioned above, knowledge of available dive depths is critical to better specify the semi-autonomous dive. For an approximate extension of the structure of the water body, the water body can be marked out in advance in the dry dock. But this only counts for the surface of the water body. The structure at the bottom of the water body cannot be determined here. To determine the depth, the most useful determination is a sonar. A small sonar called Deeper can be used here. It determines individual measuring points in the depth and has a built-in GPS so that the measuring points are directly georeferenced. Using these points, a depth map can be created via QGIS and Grass, so that areas between the individual measurement points can also be discussed. Within the project a depth map of the reservoir in Oberwartha was created (Figure 3) (Balletti et al., 2015; Papadimitriou et al., 2015).

Likewise, it is important to know at what depths documentation is to take place in order to make provisions for both hardware and software. Therefore, pre-mapping is crucial, since for the creation of the videogrammetric 3D model the distance to the bottom should always be quite equal. Therefore, a second sonar was attached directly to the submarine to make it easier for the boat to keep the distance to the bottom.

4. Conclusions and Future work

In the future, different sample removal strategies will be compared to investigate which is the best solution for each case study. Thereby a small portfolio will be created in which one can choose the appropriate sampling for the respective mission. The sonar, which is already mounted on the submarine, is to automatically adjust the depth in a further development stage to enable gliding over the bottom at the same distance. This will lead to improved data acquisition and better 3D models. (Block et al., 2015).

Conflicts of Interest Disclosure

No potential competing interests have been reported by the authors.

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