Automatic georeferencing for 3D underwater reconstructions using indirect GPS information

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Motivation and Introduction

Since GPS is not easy to receive underwater, localisation in partial documentation is still a great challenge [Balletti et. al. 2015]. Furthermore, the working time of a research diver is limited and requires special safety precautions [Papadimitriou 2015]. Within the Archaeonautic project, we have focused on the development and expansion of cost-effective mini-submarines. Significant diving depths can be reached without great precautions, and decompression stops of divers can be avoided. Typically, these mini submarines communicate with the base station via a long cable. Within the project, we developed a buoys solution where a radio link replaced the cable. Thus, the cable could be reduced to the length of the diving depth.

However, other problems arise when using mini-submarines. Apart from the additional difficulties in initialising the tracking due to the light conditions as well as ground and water conditions, simple underwater localisation is unfortunately not possible, since due to their wavelength, GPS signals cannot be transmitted through the water as a medium. With the GPS receiver in the buoy, the position of the buoy on the water surface is always known [Block et. al. 2018].

Automatic positioning of the submarine relative to the buoy

This position can be used as a reference value. Within the system, the diving depth, cable length, speed, and direction of travel from the submarine are also known always. In addition, there is a pre-defined driving scheme, which within this project is a double grid with adjustable length of the parallel tracks depending on the documented area (Fig. 1 left).

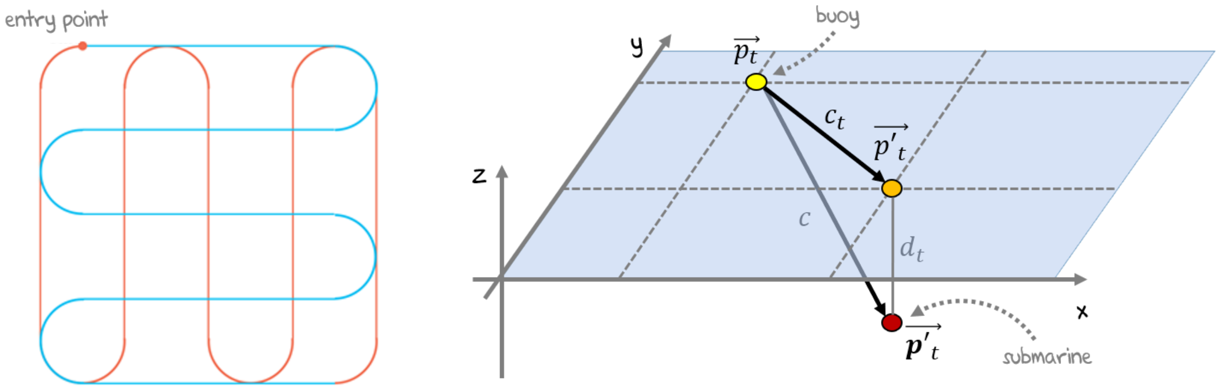


Fig 1. The left figure shows the driving strategy used for the documentation. The mini-submarine travels as long as possible in a straight line in an orthogonal net. As soon as the submarine maintains the same direction for a specific time, it can be assumed that it is on one of the tracks. In this case, the ideal situation is shown on the right, and then the position of the buoy can be deduced from the position of the submarine.

If the submarine and buoy are moving in the same direction for a specific time t_c (Fig. 1 right), ensuring that the cable connection is fully extended, with a current diving depth d_t, constant cable length c and a given buoy velocity $\overrightarrow{v_t} = (v_t.x, v_t.y)$ at the surface of the water, we can estimate the maximum for t_c as follows:

$$t_c = 2 \cdot \frac{\|\overrightarrow{v_t}\|}{\sqrt{c^2 - d_t^2}}$$

The position $\overrightarrow{p'_t} = (p'_t.x, p'_t.y)$ of the submarine relative to the water surface at time t depending in the position $\overrightarrow{p_t} = (p_t.x, p_t.y)$ of the buoy at the same time can be determined precisely on the water surface:

$$\overrightarrow{p'_t} = \overrightarrow{p_t} + norm(\overrightarrow{v_t}) \cdot c_t$$

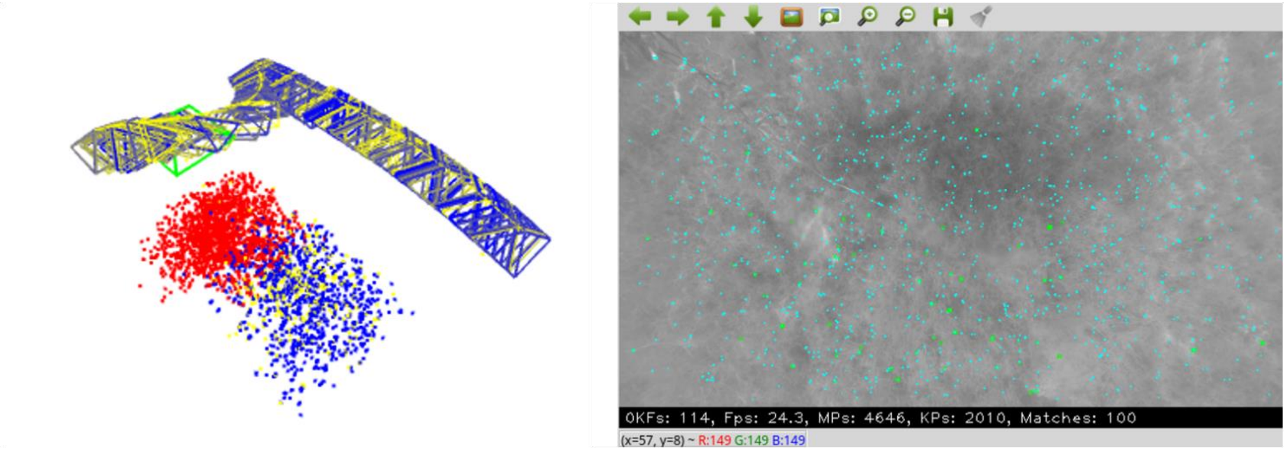
Here, c_t does the Pythagorean theorem easily give the current distance relative to the water surface

$$c_t = \sqrt{c^2 - \boldsymbol{d_t^2}}.$$

In the right-handed coordinate system, the position of the submarine can now be extended by the depth d_t to a 3-dimensional coordinate, by $\overrightarrow{\boldsymbol{p'}_t} = (p'_t.x, p'_t.y, -d_t)$. The exact position of the submarine in relation to the buoy is known and thus the exact position of the submarine within the map of the surroundings generated during the journey. However, this can only be used if the submarine travels a straight line. Otherwise, the distance between the mini-submarine and the buoy cannot be determined quickly due to the curvature of the cable. In the system we save the GPS Information of this Positions on the frame of the camera.

Live reconstruction using ORB-SLAM3

ORB-SLAM3 is used so that the position of the mini-submarine can also be determined during other manoeuvres. This software creates a map from recorded video material. Since the previously presented variant is used to determine an exact position from time to time, this information can also be incorporated into this algorithm and improve it. Thus, within the algorithm, individual camera positions can be evaluated as better (Fig. 2) [Campos et. al. 2020, Mur-Artal 2017].



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0KFs: 114, Fps: 24.3, MPs: 4646, KPs: 2010, Matches: 100
(x=57, y=8) ~ R:149 G:149 B:149
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Fig. 2. ORB-SLAM3 at runtime. On the left, the individual camera positions (keyframes) are colour-coded in rectangles regarding their accuracy. Blue rectangles show the keyframes which are rated as useful. The keypoints of the current frame is shown on the right. The green ones could be matched with the previous frame.

It is essential to transform the position data received via GPS and to convert it into a form usable for ORB-SLAM3 so that the evaluation of the camera positions is reliable. This should be realisable both in post-processing with complete log files and at runtime on-site with live transmission of the required data.

Within the project, the monocular vision version of ORB-SLAM3 is used, which is cheaper and lighter in weight compared to the required equipment for the stereo vision or RGBD versions. In this method, there is only one camera, from which the keypoints of the current keyframe are compared with the previous ones to determine an optimised pose. With a monocular vision, the scaling cannot observe easily. During tracking, a drift becomes more and more noticeable, which must be compensated by the camera parameters, additional calculations, and good diving strategies. Within the algorithm it is possible, that if the submarine is in a known location it realised it and if the position is not the same like estimated it corrects all points since the last time it was on this position. This is called Loop-closing. As Fig 1 shows, the driving strategy tries to make it possible to hit the same points as often as possible.

Automatic georeferencing

Now there is a cloud of points with keyframes, and some of them are georeferenced. To ensure that the model can then be well referenced, three keyframes or camera positions should now be used within the model so that the largest possible area can be covered (Fig. 4).

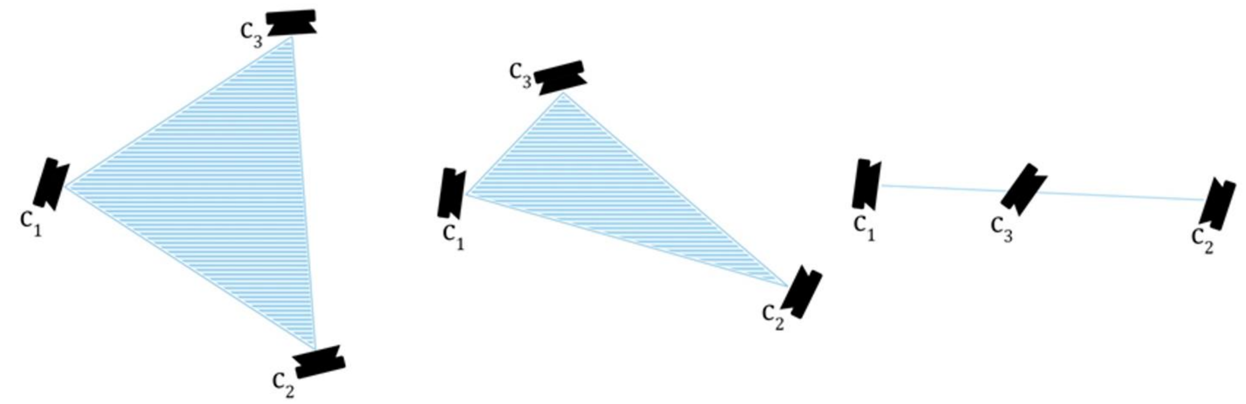

Fig. 4: To reference a model that has been created, camera positions that are far away should be selected. These should, at best form a large triangle. On the left is an almost perfect model. The triangle covers as large an area as possible. On the right, you can see the almost worst scenario. In connection with the used travel strategy, it becomes clear that the longer the submarine travels, the larger the area that can be spanned.

To find a large triangle, the points furthest of the triangle should use for reference. The angle between the points should be as close as possible to $60°$. With this good camera positions, it is possible to rescale the whole point cloud of ORB-SLAM3.

These included points are in the model from the better-evaluated camera positions, can be evaluated higher in the point cloud. The more good camera positions receive individual points, the better they are. These can be used very well as reference points. They are also used to equalise the model (Fig. 3).

Fig. 3. Four camera positions can be seen on the left, with blue being the well-referenced ones. C_2 *is a well-referenced camera position. Therefore, all points recorded by this camera are considered good. In the right picture, three furthest camera positions are highlighted to be selected for referencing the model.*

Within this spanned area, the individual map points of the point cloud, as shown in Fig. 3. on the right, are to be examined more closely. These have a corresponding change of their own position due to the position of the keyframes, which was adjusted with the georeferencing. By assigning the original position of the map points to their newly determined position and determining the distance between both points, the resulting error can be determined.

The previously defined requirement for the largest possible area under consideration helps to keep the error in the smallest possible size range.

The longer the mini-submarine is on the move, the more good camera positions that span a large area underneath can be found and the more accurately the points can be referenced. However, there is the possibility that the necessary power for all processing steps and the associated computing time will increase to a higher degree than can be accepted for the requirements within this project.

Conclusion

The algorithms and connection of the different sensors presented in this paper showed how ORB-SLAM3, in combination with the GPS signal of the buoy can determine a relatively accurate position even without GPS underwater. Further procedures would be to include more sensors in the calculation for a more precise determination.

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