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Poster: Self-Localization of Micro AUVs Using a Low-Power, Low-Cost Acoustic Modem

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ABSTRACT

A variety of underwater monitoring tasks, such as localization of pollution sources, measuring of water quality and inspection of sheet pilings can be facilitated by the use of small and cheap micro AUVs. To set the measurements in a spatial context a robust and precise self-localization of every robot is required. In this paper, we show that a cheap and small acoustic modem is everything you need for a position estimation with an error in the sub meter range.

CCS CONCEPTS

• **Computer systems organization → Robotic autonomy**; Embedded systems; • **Hardware →** *Wireless devices*;

KEYWORDS

underwater, acoustic communication, localization, ranging, auv

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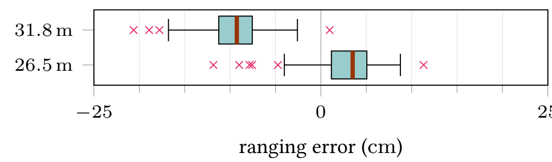

Figure 1: Error distribution of ranging with hydrophones at distances of approx. 26.5 m **and** 31.8 m **(measured w. tapeline).**

1 INTRODUCTION

Wireless monitoring and sensing has been widely adopted for many scenarios , also including underwater applications such as leakage detection of ships, harbor basin inspection, and monitoring of industrial inlets. Most of these tasks are not stationary, making the usage of a static sensor network impracticable. Furthermore, fast reaction times and high spatial resolution are needed, making the deployment of a single sensing device also infeasible. To fulfill these requirements, the usage of small and low-cost autonomous underwater vehicles (μAUVs) such as MONSUN [5] or HippoCampus [4] is advisable. A length of less than 1 m enables the usage in narrow places and agile navigation. The deployment of μAUVs (possibly in certain formations or swarms) relies on the availability of communication and localization underwater.

Various communication devices for underwater applications exist, often either with a price exceeding the cost of the μAUV or with a size being larger than the μAUV. This renders the use of μAUVs uneconomical and hampers their practical application in research projects. We hence developed a small and low-cost acoustic underwater modem that we presented in [6]. Furthermore, several underwater localization algorithms have been presented by the research community in the recent years as shown in [3, 7]. Most of these algorithms are not suitable for our use case. Centralized approaches (e.g. ALS [1]) cannot be used for self-localization of swarm members. Techniques requiring stationary anchors like UPS [2] are not applicable, as they contradict the flexible deployment of mobile swarm robots without infrastructure. Algorithms relying on synchronized nodes or using multiple receivers for angle of arrival estimation are raising cost and complexity and are therefore not applicable. This holds for all techniques introducing additional hardware like sonar or doppler velocity logs (DVL).

Contributions. We investigate the feasibility of self-localization solely relying on our small, low-cost and low-power underwater acoustic modem. The localization approach does not require fixed anchors, does not rely on time synchronization between nodes, and is non-centralized. We describe the localization algorithm, present a real-world experiment for the static case and simulate its usability and performance for the mobile case.

2 RANGING

For distance-based self-localization an accurate distance measurement between nodes is needed. The distance of μAUVs is commonly between 5 m to 100 m in the targeted use case, so the accuracy of the distance measurements should be in the sub-meter range. As described in Sect. 1, communication, ranging and localization should be done by one single device in the μAUV to lower cost and complexity. Due to extremely low data rates of only a few hundred bit per second, our modem provides distance measurements piggybacked on standard communication packets to save bandwidth. By setting a flag in a transmitted packet, the μAUV can request a distance measurement to its neighbor. On reception of this packet the neighbor answers with an acknowledgement. With this two-way communication the initiating μAUV can determine the time-of-flight of the signal. By applying the speed-of-sound in water (which

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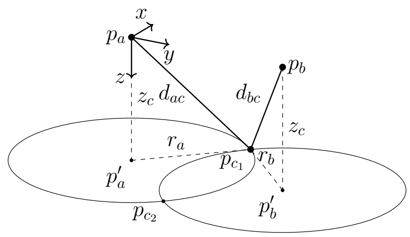

Figure 2: Projection of p_a and p_b into the plane of p_c. To determine the solutions for p_c and p_c, we use the measured distances d_{ab} and d_{ac}.

can be pre-programmed at mission start or measured by the on-board-sensors) the distance to the neighbor is calculated. Fig. 1 shows that the average precision of our ranging method is at most 10 cm and therefore precise enough for self-localization of μAUVs. We also did measurements for 90 m and 150 m, which have nearly the same precision, but are omitted in Fig. 1 as we are lacking an accurate ground truth measurement.

3 LOCALIZATION

The general goal of self-localization is to determine the 3D-position of a robot in x, y, and z-direction. As μAUVs are usually equipped with a depth sensor, we can assume that the z-coordinate of each robot is known up to a precision of a few cm. We also assume that μAUVs are equipped with GPS, so non-submerged robots can determine their x and y position. For the discussed use cases the robots will be deployed in formations with distances of several meters, so the accuracy of GPS is assumed to be sufficient. If this is not the case, DGPS can be used, providing mm accuracy. Position of non-submerged nodes is used as reference for localization. At the beginning of a mission, every robot is at the surface and its (x, y)-position is known. After submersion, however, the (x, y)-position becomes unknown and must therefore be determined by a localization process.

In the following, we assume that we always have at least two μAUVs a and b at the surface, acting as mobile anchors. The position of these anchors is defined by $\boldsymbol{p}_a = (x_a, y_a, z_a)$ and $\boldsymbol{p}_b = (x_b, y_b, z_b)$, where $z_a = z_b = 0$. To begin the localization process, a robot c at position $\boldsymbol{p}_c$ and unknown x_c, y_c sends out a packet with the ranging-request flag set. a answers this request with an acknowledgement containing its own location. b does the same after overhearing the packet sent by a or after a timeout. After this procedure c knows the positions $\boldsymbol{p}_a, \boldsymbol{p}_b$ and the distances to a and b, denoted by d_{ac} and d_{bc}. To calculate the position of c, we project the spheres with radius d_{ac} around a and radius d_{bc} around b to a horizontal plane in depth of z_c as shown in Fig. 2. W.l.o.g. we can assume that anchor a always is at $\boldsymbol{p}_a = (0, 0, 0)$. We obtain two circles around a and b described by

$$r_a^2 = x_c^2 + y_c^2, \quad r_b^2 = (x_c - x_b)^2 + (y_c - y_b)^2. \tag{1}$$

Due to the projection into the depth of c, r_a and r_b are

$$r_a^2 = d_{ac}^2 - z_c^2, \quad r_b^2 = d_{ab}^2 - z_c^2. \tag{2}$$

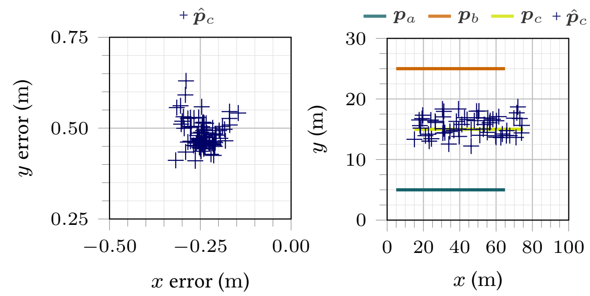

Figure 3: Left: localization error during outdoor experiment with anchors at $(25.4, 19.3)$, $(-17.4, 20.8)$ and node at $(0, 0)$. Right: results of simulation with moving nodes ($1\,\mathrm{m\,s^{-1}}$) and localization every 2 s. $\hat{\boldsymbol{p}}_c$ denotes the estimated positions.

The two circles have two intersections, representing the two possible locations $\boldsymbol{p}_{c_1}, \boldsymbol{p}_{c_2}$ of node c. The point closer to $\boldsymbol{p}_c$ calculated in the previous localization round is chosen as new estimated position. The error of our ranging is smaller than the expected distances of the robots by one order of magnitude, so this is a feasible approach.

4 PRACTICAL EVALUATION & SIMULATION

To show that our proposed localization approach based on distance ranging allows a robust and precise self-localization in the static case, we conducted an outdoor test at a marina in Hamburg-Finkenwerder. Three hydrophones were deployed in a triangular shape. We sent 100 ranging requests, one every 2 s and in 79 % both answers were received. Localization was only done if both answers were received, runs in which only one answer (19 %) or even none (2 %) was received were skipped. To obtain a ground truth, we measured the distances of the hydrophones with a tapeline on the jetties. The results of self-localization, shown in Sect. 4, reveal that we are able to obtain a very precise position with a variance of 3.54 cm in x-direction and 3.97 cm in y-direction. The mean error of our obtained ground truth was 24.25 cm in x-direction and 48.42 cm in y-direction. This leads to a mean euclidean distance error of 54.15 cm, resulting from acoustic reflections at the water surface and from an inaccurate accurate ground truth (jetties not orthogonal, hydrophone moved by currents).

To extend our findings to the mobile cases, we conducted simulations with the ns-3 network simulator. A swarm of three nodes, swimming in V-formation is deployed. The non-submerged nodes are allowed to access their absolute position, while the submerged node is not. To simulate GPS error, we add Gaussian noise with a standard deviation of 2 m, which is a realistic value for the MTi-G-710 receivers that are built into MONSUN. We add noise to the depth of the submerged robot to simulate the error of the depth sensor. Accuracy of the distance measurements is the same as found out during real-world tests depicted in Fig. 1. During simulation the robots move along a pre-defined path, simulating the inspection of a port basin. We adjusted the simulation to practical conditions as they would occur during the designated use cases and, as shown in Sect. 4, localization error is small enough for them.

5 CONCLUSION AND OUTLOOK

We analyzed the feasibility of self-localization of μAUVs using a small, low-power and low-cost acoustic modem by providing real-world experiments for the static case and a simulation for the mobile case. We showed that underwater self-localization is possible with only a single, low-cost and very small transmitting device. Next, we will conduct outdoor tests for the mobile case to analyze the achievable accuracy of position detection for a submerged μAUV.

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