ILS: Instant Localization Scheme for Underwater Mobile Networks

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I. Introduction

Mobile underwater networks have recently been proposed as a way to explore and observe the ocean with a wide area coverage at reasonable cost when compared to traditional tethered approaches (e.g., seabed sensors) [1]–[4]. To achieve this goal, a swarm of mobile sensors, e.g., Autonomous Underwater Vehicles (AUVs) such as REMUS and IVER2 or floats such as UCSD Drogues [5], can be deployed to the venue of interest for short-term *ad hoc* real-time aquatic missions such as oil and chemical spill monitoring, submarine detection, and surveillance. Mobile nodes monitor local underwater activities and report collected sensor data using acoustic multi-hop routing to other mobile nodes for collaboration or to a distant data collection center.

In all of these applications, localization plays an important role since detected events must be tagged with location information. Moreover, location information is also required for geographical routing. However, GPS is not available in underwater because radio waves cannot propagate through water. To achieve this, conventional oceanographic technology uses two types of systems to localize nodes: Long Base-Line (LBL) and Short Base-Line (SBL) systems [6]. In both, the sensors position themselves based on acoustic communications with a set of *localized* transponders. In LBL the transponders are deployed on the seafloor or under surface moorings around the area of operation. In the SBL system, a ship follows the sensors and uses a short-range emitter to enable localization. Unfortunately, both techniques are expensive and require long planning for deployment. Alternatives have been recently investigated. In DNR [7], the Erol et. al. propose the use of mobile (sinking) beacons to increase the localization coverage in 3D space. Beacons dive and rise to act as underwater GPS. In turn, localized nodes also can act as beacons, enabling multi-hop localization. In underwater sensor networks, battery power limitations are critical. To save power, protocols must economize message exchange. However this process is extremely power hungry due to the diving and rising movement and frequent update message exchange amongst deployed nodes.

In this paper, we propose an Instant Localization Scheme (ILS), which uses only the onboard accelerometer, compass, and hydraulic pressure gauge readings and the acoustic sound propagation delay between the monitoring center and AUVs. In this scheme, exchanging beacon signals between the monitoring center and AUVs will provide the distance between them. With the displacement and direction updates of AUVs and the exchanging of information, AUVs can pinpoint their locations from the monitoring center. Note that this scheme does not rely on traditional trilateration to localize AUVs but use only distance and angular information from monitoring center which is already localized by receiving GPS signal. The following are the key features of ILS:

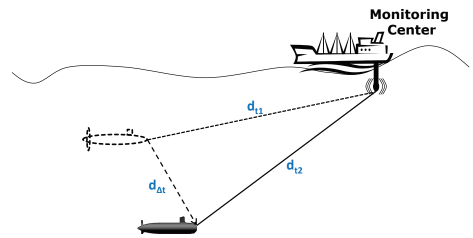


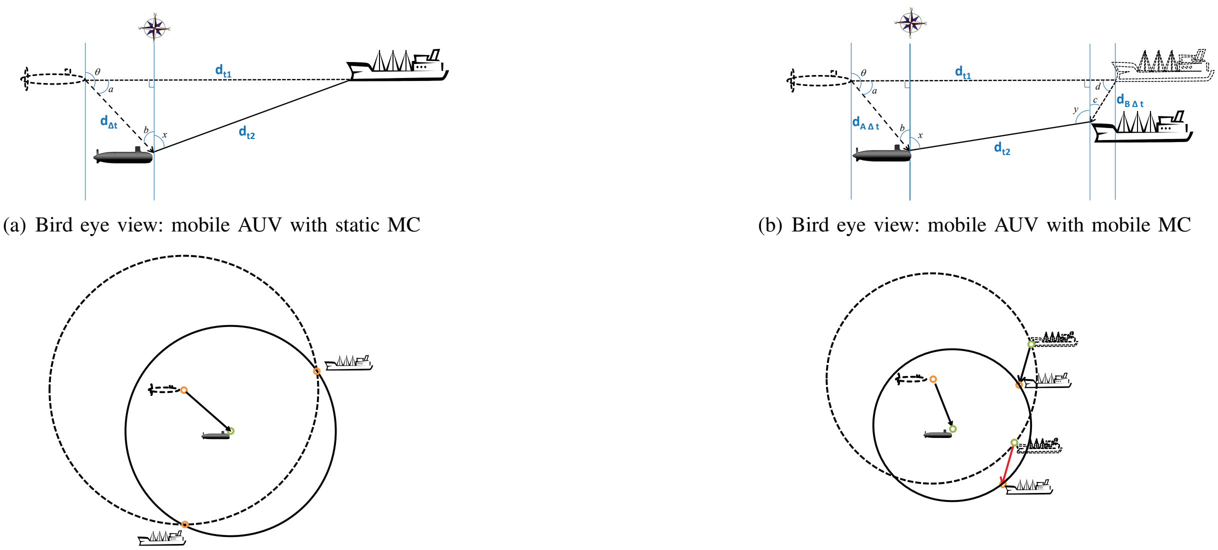
Fig. 1. Target scenario: one mobile AUV with static MC

- Easy to deploy: no extra operations such as installing anchor nodes or displacement to surface to receive GPS signal
- Precise: This scheme does not introduce cumulative error caused by the dead reckoning process because it relies on instant propagation delay between two nodes and accelerometer and compass updates.

II. ILS Prerequisite

As the underwater research community adopts acoustic wave as a means of underwater communication, we are confronted with severely limited bandwidth, long propagation delays (1.5km/s, five orders of magnitude slower than radio signals in terrestrial communication), and relatively high transmission energy cost (reception to transmission power ratio of 1:125 [8]). However, long propagation delay makes it possible to provide accurate distance information between two nodes with reliable accuracy. With state of art acoustic modem technology, acoustic modems can support sampling frequency of 44.1kHz [9]. Considering a typical setting of 1.5km/s and 44.1kHz, the distance granularity is then about 3.4 centimeters. The granularity will be further improved if higher sampling frequencies can be afforded. However, to localize one mobile node, we need an exact projection to an imaginary point with the distance.

Fortunately, given that the onboard hydraulic pressure gauge can accurately estimate depth (avg. error $<$ 1m [10]), our projection problem in 3D is specialized to finding a direction in 2D. According to Karras et. al., a low cost IMU can provide the accelerations and angular information with reliable accuracy. With a Multisensor Kalman Filter (MKF) support, the experimental results show that the system is able to calculate a satisfactory estimate of the position and velocity vector of the vehicle with no update measurement from the Laser-based Vision System for a period of approximately 10 sec [11]. In the following Section, we will describe how to calculate the direction in 2D area with accelerometer and compass readings.



(a) Bird eye view: mobile AUV with static MC

(b) Bird eye view: mobile AUV with mobile MC

(c) Two possible MC's directions

(d) Two possible MC's directions

Fig. 2. Instant Localization Scheme: Mobile AUV with static MC and Mobile MC

III. Instant Localization Scheme

Figure 1 illustrates how we can obtain three distances and a direction of AUV's displacement. First dotted line is a distance between Monitoring Center (MC) with AUV at time $t1$ and second dashed line is displacement distance that mobile AUV has moved during Δt and its direction. The third solid line is a distance between MC and AUV at time $t2$. With these obtained three distances, a displacement direction, and measured pressure gauge level of an AUV, we can pinpoint on exact coordinates in 3D underwater space. Figure 2(a) shows the bird eye view in the same scenario in Figure 1. To calculate a direction between two nodes, we exchange beacon messages and measure the Round Trip Times (RTTs) to calculate d_{t1}. Then, we obtain acceleration and angle information from accelerometer and compass. By double-integrating acceleration, we can obtain displacement distance ($d_{\Delta t}$). Lastly, AUV and MC exchange beacon messages to get current distance (d_{t2}). Now, we can calculate the direction from AUV to MC in 2D. Due to limited information, we have two possible directions (Figure 2(c)) as follow: One direction from AUV to MC ($\angle\alpha$) can be calculated as follows:

$$\angle\alpha = \arccos\{\frac{d_{\Delta t}^2 + V_{diff} * \Delta t + d_{t2}^2 - d_{t1}^2}{2d_{\Delta t}d_{t2}}\} + \Theta - \pi \quad (1)$$

where Θ denotes AUV's displacement direction, d_{t1} denotes distance between AUV and MC at time $t1$, $d_{\Delta t}$ denotes AUV's displacement distance during Δt (i.e., $t2 - t1$), V_{diff} denotes water current velocity difference between AUV and MC (note that different depth introduces different water current speed), d_{t2} denotes distance between AUV and MC at time $t2$.

The other direction from AUV to MC ($\angle\alpha$) can be calculated as follows:

$$\angle\alpha = \Theta + \pi - \arccos\{\frac{d_{\Delta t}^2 + V_{diff} * \Delta t + d_{t2}^2 - d_{t1}^2}{2d_{\Delta t}d_{t2}}\} \quad (2)$$

Figure 2(b) shows another scenario that both AUV and MC are mobile. To calculate the direction to each other, we need to draw two circle based on circle equations according to displacement and distances, namely d_{t1} and d_{t2}. Then, we define two vectors based on AUV's and MC's displacement directions and distances during Δt. Then, we can define four equations based on these conditions. Equations are omitted in the interest of space. As depicted in Figure 2(d), we finally have two possible directions between AUV and MC.

IV. Future Work and Conclusion

In this paper we propose an Instant Localization Scheme (ILS), which uses only the onboard accelerometer, compass, and hydraulic pressure gauge readings and the acoustic wave propagation delay between the monitoring center and AUVs. To verify performance of our scheme, we are currently implementing ILS on smart phones due to easy accessibility to ground truth on the terrestrial environment.

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