Extended Abstract: Uncertainty-Based Localization Solution for Under-Ice Autonomous Underwater Vehicles *

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ABSTRACT

Localization under-ice is challenging due to the increased difficulty of accessing Global Positioning System (GPS) or deploying localization infrastructure. In this work, a novel solution that minimizes localization uncertainty and communication overhead of under-ice Autonomous Underwater Vehicles (AUVs) is proposed. Our solution is compared against existing solutions, which shows improved performance.

Categories and Subject Descriptors

C.2.1 [**Computer Systems Organization**]: Network Architecture and Design—*Network Communications, Wireless Communication*

General Terms

Algorithms, Design, Performance

Keywords

Localization, Position Uncertainty, Communication Overhead

1. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) are widely believed to be revolutionizing oceanography as they can enable research in environments that have typically been impossible or difficult to reach. For example, AUVs have been used for under-ice ocean exploration to study the impact of climate change to the circulation of the world's oceans. These AUVs need to know their own positions for under-ice exploration. Due to the inaccessibility of Global Positioning System (GPS) underwater, over time, inaccuracies in models for deriving position estimates, self-localization errors, and drifting due to ocean currents will significantly increase the uncertainty in position of underwater vehicle. Moreover, in extreme environments such as under ice, surfacing of AUVs to get a GPS update is hardly possible and, therefore, position information is highly uncertain. It is also difficult to rely on localization infrastructure as it requires great deployment efforts before operation and the operation range is limited by the infrastructure. Deployment of multiple AUVs to perform one mission becomes a widely-adopted option, enabling new types of missions through cooperation and information sharing among AUVs. Existing localization schemes are generally not able to estimate the uncertainty associated with the calculated position, which is high in under-ice environments, and thus are not able to minimize position uncertainty.

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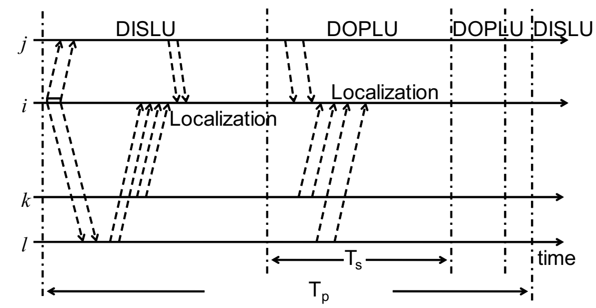


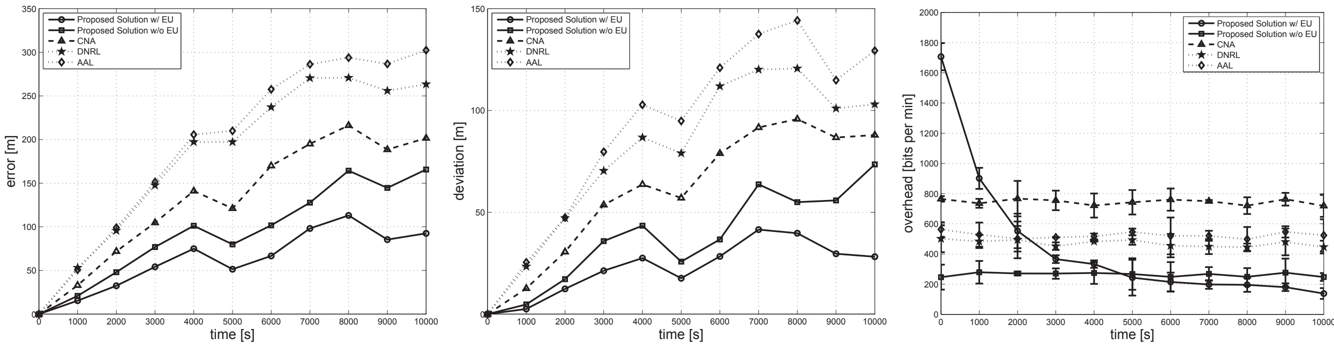
Figure 1: Overview of the proposed approach.

To address this problem, we propose a solution that uses only a subset of AUVs as reference nodes for position estimation without relying on localization infrastructure. We propose a probability model to estimate the position uncertainty associated with localization techniques (which include a novel Doppler-based localization technique that exploits ongoing communications for localization). Two algorithms, one to minimize location uncertainty and the other to minimize the localization overhead, are also proposed.

2. PROPOSED SOLUTION

Due to the high uncertainty in position of an underwater vehicle, using a deterministic point is not enough to characterize the position of an AUV. Such a deterministic approach underwater may lead to problems such as routing errors in inter-vehicle communications, vehicle collisions, loss of synchronization, mission failures. In order to address such problems, we introduce an uncertainty model to characterize a node's position. Depending on the view of the different nodes, two forms of position uncertainty are defined, i.e., *internal uncertainty*, the position uncertainty associated with a particular entity/node (such as an AUV) *as seen by itself*, and *external uncertainty*, the position uncertainty associated with a particular entity/node *as seen by others*. These uncertainty regions and the distribution of the nodes in these regions can be modeled as the confidence regions in statistics, which can then be estimated using statistical methods such as that in [1].

In this work, using the notion of external uncertainty, we can model the uncertainty associated with localization techniques. Based



(a) Localization error comparison (4 AUVs) (b) Deviation comparison (4 AUVs) (c) Communication overhead

Figure 2: Preliminary simulation results under the ice mission with resurfacing ('w/ EU' and 'w/o EU' denote 'using' and 'not using' the external uncertainty notion, respectively).

on this uncertainty, optimization problems are formulated to minimize localization uncertainty and communication overhead. As shown in Fig. 1, our solution consists of two phases, the distance-based localization with uncertainty estimate (DISLU) and Doppler-based localization with uncertainty estimate (DOPLU). DISLU relies on packets (i.e., communication overhead) to measure the inter-vehicle distances (i.e., ranging), which, in conjunction with positions of reference nodes, are utilized to estimate the position. On the other hand, DOPLU, which measures Doppler shifts from on-going communications and then uses these measurements to calculate velocities for localization, removes the need for ranging packets. As DOPLU only relies on relative measurements, it may not be able to fix displacement errors introduced by the rotation of the AUV group. In this case, DISLU is executed to bound such localization errors. Using the uncertainty model, the localization error and communication overhead of DISLU and DOPLU can be jointly considered and algorithms are devised to minimize the localization uncertainty and communication overhead while satisfying localization error requirement.

As shown in Fig. 1, each AUV first runs DISLU using the distances measured from the round-trip time. Then, DOPLU is run using Doppler-shift information extracted from inter-vehicle packets after T_s, the duration for which enough Doppler shifts are collected to estimate the position. DISLU is run to fix the localization error introduced by DOPLU after T_p, which is the time since the last DISLU is started.

Both DISLU and DOPLU use the external uncertainty and corresponding probability distribution function (pdf) to estimate the uncertainty resulting from the localization technique, i.e., the internal uncertainty and pdf of the AUV running the localization algorithm. Then this internal uncertainty information is broadcast in order for other AUVs to estimate external uncertainties. Our previous work in [1] provided a statistical solution to estimate the internal and external uncertainty, which is used for initial estimation here.

Obviously, localization using different references leads to different estimation of internal uncertainty and corresponding pdf. To minimize the estimated internal uncertainty, this can be achieved by solving an optimization problem. To measure the degree of uncertainty, we use *information entropy* as the metric. With this metric, the solution to the optimization problem can select a subset of references that minimize the estimated internal uncertainty.

To further minimize the communication overhead, we need to find the optimal T_s and T_p while keeping the localization uncertainty low. T_s is dynamically adjusted by multiplying the measured average time between consecutive on-going communications with the minimum number of on-going packets to run DOPLU. T_p can be calculated to be the maximal time where the probability of the position displacement estimated by DISLU and by DOPLU being greater than a threshold is within a specified probability threshold.

3. PRELIMINARY RESULTS

Our solution is compared against AAL [2], DNRL [3], and CNA [4], which are existing solutions designed for underwater localization using AUVs. We modify AAL, DNRL, and CNA accordingly so that they work in the under-ice environment. Two metrics, the *localization error* and the *deviation of error*, are used, where the former is defined as the distance between the actual and the estimated AUV position and the latter is the amount the localization error deviating from the average error. Preliminary results are plotted in Fig. 2, showing that our solution performs better than AAL, DNRL and CNA in terms of localization error, deviation of error and communication overhead. This shows the effectiveness of our solution in reducing the localization uncertainty and overhead.

4. CONCLUSION

We proposed a localization solution that minimizes the position uncertainty and communication overhead of AUVs in the challenging under-ice environments. Compared with several existing localization techniques, it is shown that our approach achieves less localization errors with low localization overhead.

5. REFERENCES

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