Demo Abstract: Performance Evaluation of Underwater Vehicle Coordination Algorithms through Emulation

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1. INTRODUCTION

In recent years, UnderWater Acoustic Sensor Networks (UW-ASNs) [1] have been deployed to study dynamic oceanographic phenomena such as variations of salinity and temperature, and phytoplankton growth for environmental and disaster monitoring. To ensure sufficient coverage of the undersampled vast ocean, intelligent sampling strategies involving teams of Autonomous Underwater Vehicles (AUVs) with underwater wireless communication capabilities become essential. These AUVs should coordinate and steer through the region of interest, and cooperatively sense and transmit the sensed data to onshore stations. Underwater gliders, a class of energy-efficient AUVs that change their buoyancy with hydraulic pumps to power forward motion, have been used for long term ocean monitoring.

Acoustic communications are used to transfer information between AUVs and, eventually, to a surface station where the data is gathered and analyzed. However, acoustic communications are influenced by path loss, noise, multi-path, Doppler spread, and high propagation delay, which makes the channel bandwidth and bit rates limited and dramatically dependent on both range and frequency.

A number of solutions such as [2, 3] have been proposed for coordination of AUVs. These solutions are either evaluated using software simulators or real underwater testbeds. However, software simulators cannot completely capture the characteristics of real acoustic modems such as transmission delays between communication pairs, while experiments on real testbeds are usually expensive and time consuming, and so are the field deployments at the ocean. To overcome these limitations, we developed an emulator that fills the gap between the existing methods for simulation and field trials. Our emulator can increase the accuracy of the simulation environment by using a hybrid approach. It has the same modem interfaces used by underwater vehicles so that - once proven in the emulator - a communication protocol may be used for field testing without major changes. Moreover, underwater vehicle coordination algorithms, i.e., team formation and steering algorithms, can also be implemented and tested on our emulator.

To illustrate the use of our emulator, we propose a demo of our underwater glider coordination algorithms introduced in [4] using the WHOI acoustic Micro-Modems. Using a Graphical User Interface (GUI), the user can specify different number of gliders, team formation geometries, and steering trajectories as well as related parameters such as ocean current models, current directions, current velocity/intensity, and communication parameters. With 3D visualization of the movement of the vehicles, the user is able to evaluate the effect of ocean current and underwater acoustic communication impairments on the vehicle coordination algorithms. Hence, the feasible regions of the algorithms can be studied.

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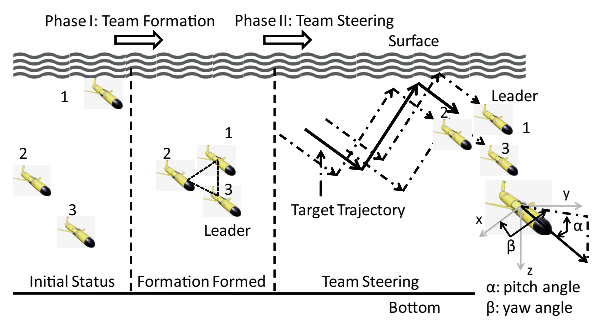

Figure 1: Overview of the proposed solution for team formation and steering.

2. TEAM COORDINATION ALGORITHMS

In [4], we proposed novel algorithms to form a team of gliders into a specified geometry and steer through the 3D region of interest to take measurements in space and time. As depicted in Fig. 1, given i) the number of scattered gliders, ii) the corresponding geometry formation, and iii) the target trajectory, two phases of operations are required to perform the monitoring mission: 1) the selected gliders need to be mapped into a specified geometry formation making sure that no glider collisions occur (*Phase I*); 2) after the first phase, the team needs to steer through the region of interest along the predefined trajectory while maintaining the formation (*Phase II*).

In Phase I, an algorithm was proposed in [4] to minimize the time to form the specified geometry under a sufficient condition to avoid vehicle collision. In Phase II, we use a hybrid approach that can reduce the communication overhead for position information dissemination. The hybrid approach selects a corresponding distributed algorithm to keep the team formation depending on whether the position information is *absolute* or *relative*. Specifically, *Absolute Formation Adjustment (AFA)* is used when absolute geographic positions of the gliders are available; whereas *Relative Formation Adjustment (RFA)* is used when relative position information between gliders is available. The RFA algorithm is based on the relative inter-glider velocity estimated by measuring the Doppler shift of ongoing inter-vehicle communications so extra overhead is not needed.

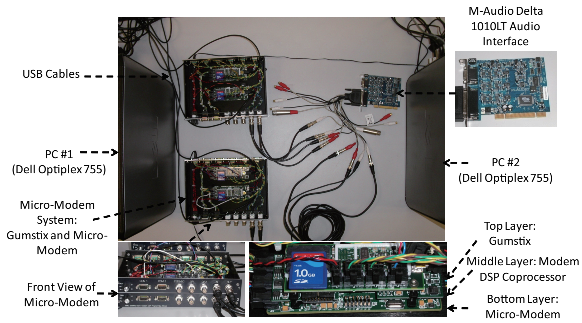

Figure 2: Physical architecture.

3. DEMONSTRATION EMULATOR

Our solution is closely coupled with the functionalities of WHOI Micro-Modem and emulator. Therefore, in this section, we present the physical architecture of our underwater network emulator [5]. The emulator relies on a multi-input multi-output audio interface that can process real-time signals to adjust the acoustic signal gains, to introduce propagation delay, to mix the interfering signals, and to add ambient/man-made noise and interference.

When the emulation starts, the Emulation ConTroLler (ECTL) program at PC #1 issues commands to the channel emulator at PC #2, which will then start to emulate the channel according to the parameters provided. ECTL then requests the Gumstix Motherboards (GMs) to run their network tasks. Whenever a packet is transmitted or received, the GMs inform the ECTL via USB connection so that ECTL can collect the emulation results and issue further commands.

Upon receiving the command from PC #1, channel emulator at PC #2 will adjust the gains of input signals, mix them, introduce propagation delay, add ambient noise, and route the processed signals to the corresponding outputs. Acoustic signals are processed in real time using real-time audio processing package *playrec* [6].

4. PROPOSED DEMONSTRATION

As shown in a preliminary snapshot reported in Fig. 3, our demo will be a 3D visualization of the movement of underwater gliders using our team formation and steering algorithms. On-going communication activities among the gliders will also be visualized with statistical metrics, such as link quality (Fig. 4), link latency, received signal strength, received Signal-to-Noise Ratio (SNR) and energy consumption, and will also be plotted in real time.

Our demo is designed to be flexible so that parameters of the algorithms can be configured through a GUI. In addition to the glider parameters and the 3 required inputs mentioned in Sect. 2, the user can select different ocean models and specify current direction and velocity so as to see the effect of ocean currents on the algorithms. The user can also choose different communication parameters such as underwater propagation models, packet types (i.e., modulation, channel coding, and bit rate) and packet length (i.e., number of frames within a packet), in order to see the effect of underwater communications on the algorithms. As a consequence, the user will see how well the team formation and steering algorithms work in different configurations and hence explore the feasibility region of the algorithms. Our demo adopts a modular design so that different team formation and steering algorithms can be replaced and tested without changing the other components.

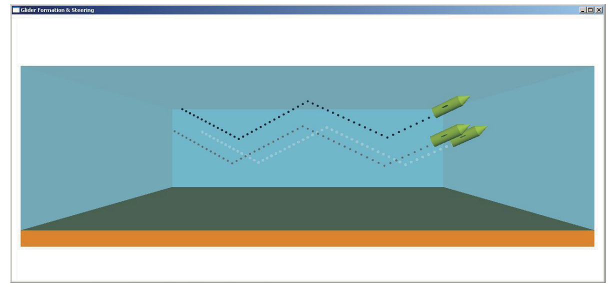

Figure 3: Visualization of 3 gliders forming a equilateral triangle.

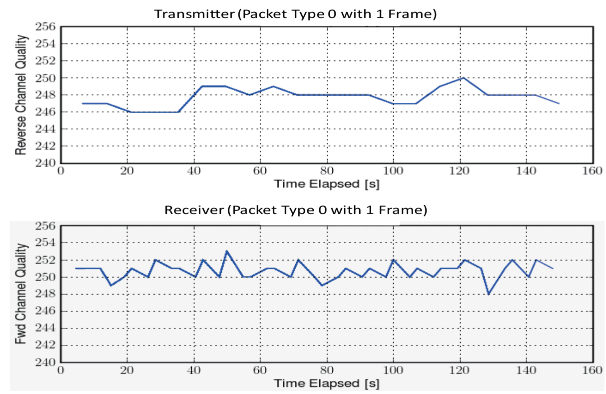

Figure 4: Snapshot of forward and reverse communication channel quality.

The demo requires the following equipment (which we will provide): 1) Four sets of WHOI Micro-Modem & Gumstix Motherboard; 2) One M-Audio Delta 1010LT Audio Interface; 2) One Desktop PC; 3) One Laptop; 4) Four USB A/Mini-B 4-pin Cables; and 5) Two Ethernet Cables.

In order to run the demo, we will need 1) a standard demonstration table, 2) Ethernet connections to our desktop and laptop, and 3) a power strip with more than 4 outlets.

5. REFERENCES

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