

Networked Sensor Swarm of Underwater Drifters

Thomas Bewley, Paolo Casari, Andrew Cavender, Peter Franks, Jules Jaffe, Ryan Kastner, Diba Mirza, Saam Ostovari, Paul Roberts, Curt Schurgers, Michele Zorzi

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Abstract- We have proposed a novel cyber technology for observing bio-physical and chemical interactions within the oceans. We envision this system to consist of a swarm of autonomous underwater drifters that can organize themselves into a dense four-dimensional sampling system, in a challenging ocean environment. We have identified three major research areas that will form the cyber backbone of our system, thereby enabling it to behave as an intelligent distributed collective. These components are: swarm control and coordination, location finding and networked solutions to information sharing. This poster highlights our research findings in each of these areas and our on going effort to integrate these solutions.

Since the drifters can only control their depth, ocean currents essentially dictate their horizontal motion. A question that naturally arises is whether they are completely at the mercy of currents or whether their horizontal motion can be strategically controlled. This would be critical to organizing them into formations and maintaining a sufficient level of network connectivity. We have developed some insight into this problem by observing the patterns formed by dinoflagellates in high frequency internal waves. These organisms have the ability to depth keep (similar to our drifters) and accumulate in the troughs of internal waves, forming bands. Based on our current understanding about these interactions we are pursuing the idea of organizing the drifter swarm by leveraging from high frequency internal waves. To this end we have studied mass transport in linear and non-linear internal waves using analytical models (previously developed by us). One of our key findings is that it is possible to transport mass in linear internal waves if the floats depth-keep inside the wave. Further, maximum horizontal velocities are achieved at the pycnocline equilibrium interface. In non-linear internal waves, floats can reverse their direction of motion by crossing the equilibrium interface. These propositions have been verified in simulations. They can be tested out by having the floats survey at different depths in a stratified medium and tracking their locations acoustically.

We have developed two unique techniques for estimating the positions of the mini-AUEs and the AUE floats (vehicles previously engineered by us). These vehicles have different energy constraints and acoustic communication capabilities. The mini-AUEs being much smaller than the AUE floats have a lower energy budget and so, they are designed to only receive acoustic signals. Our first localization technique is mainly targeted towards the mini-AUEs, as it does not require them to acoustically respond or be time-synchronized. We use a differential time technique to estimate positions in 3D using stationary surface beacons. To ensure sufficient connectivity with surface beacons, communication takes place over longer distances (~3km or more). The effects of bathymetry, variable sound speed profile and other environmental factors on acoustic propagation become prominent over these long distances. Our localization algorithm takes these effects into account by using corrected TDOA estimates obtained from measured sound speed profile and ray tracing models. Simulations indicate that this technique would work well under realistic deployment scenarios. We have also developed a real-time tracking algorithm where floats collaborate to estimate their positions by acoustically communicating with each other. Locations are estimated in a distributed fashion using a message-passing algorithm (the sum-product algorithm) that operates on factor-(sub)graphs (implemented on each float). Messages are passed locally and between vehicles via acoustic broadcasts. We have implemented our tracking method in the Network Simulator-2 (NS2) using underwater extensions to the simulator (previously developed by us). This is an effort to integrate the algorithms & protocols that we are developing into a single simulation framework.

The localization and control algorithms need reliable and energy-efficient acoustic communication. To this end we are developing solutions that span all layers of the protocol stack. We are currently designing an acoustic modem that can adapt its data-rate to the underwater channel for successful data-transmission. This was motivated by the fact that different node-pairs in a network are likely to experience different UW channels depending on their locations. To test this idea we performed field tests near the Scripps Pier. Results from these tests favor the idea of rate adaption for underwater communication. Error control is another important communication component that deals with an unreliable channel. While adaptations at the physical layer increase reliability, information loss cannot always be avoided and error-control mechanisms are crucial. The performance of a number of different ARQ mechanisms was analytically evaluated using a Markov model. The model was able to accurately represent an actual underwater channel when it was trained using data from field tests. Results also confirmed that IR-HARQ consistently improves link performance compared to Type I HARQ. Lastly, we are also developing MAC protocols, which are crucial for efficient communication in a network. While a number of MAC schemes have been proposed to deal with the challenges of the underwater acoustic channel, they have all been designed for unicast communication. Many important higher layer services such as localization, time-sync and neighbor discovery rely on broadcast communication, which current UW MAC protocols do not support. We have developed a tone-based MAC protocol that specifically supports broadcast communication. This protocol is currently being integrated into the NS2 simulation framework.