VSoE RIF Report: Micro-Tomography

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Program Summary

Despite the fact that the human civilization has heavily depended on the bodies of water covering over 71% of the Earth, we know more about the surfaces of planets millions of miles away than about what lies down on the ocean floor. However, several recent studies on marine ecology and their important role in sustaining the rest of the Earth seem to urge immediate need for more and better underwater capabilities. Furthermore, in the wake of several recent naval incidents in the waters of the Korean Peninsula as well as the massive oil spill in the Gulf of Mexico, we recognize the mounting need for high resolution, in-situ underwater monitoring technology.

Therefore, our team at USC/ISI has been conducting research and development for scalable and practical technologies toward global underwater sensing since 2006. Our approach differs from the main stream techniques in that we seek to monitor the underwater physical phenomena accurately at higher resolution using a network of collaborative, low-cost, general purpose underwater sensor nodes. Unlike most underwater systems that are in existence, we also adhere to a central philosophy behind wireless sensor network to enable global sensing. Although there have been much research on wireless sensor network in terrestrial environments, changing the deployment environment from ground to water introduces several research challenges that did not manifest themselves in most prior works.

This program have adapted one of the most elegant concepts of underwater monitoring called Ocean Acoustic Tomography onto our underwater testbed and extend its capability with new research ideas of our own. Through this research, we will build one of the first minimally invasive, marina-scale in-situ underwater temperature and current sensor using underwater wireless acoustic sensor network. We have three concrete objectives, each with tasks that depict new contributions in the field while providing support and validation to the subsequent tasks. They are (1) Marina-scale ocean acoustic tomography (micro-tomography), (2) deep water Micro-tomography, and (3) ultra-low power sensor PHY and communication protocols.

(For additional information go to http://oasys.isi.edu/pages/projects)

New Outcome and Impact

Using a sensor network for acoustic tomography enhances or enables a number of ecological and defense applications. Many marine organisms are temperature sensitive, however the dynamic spatial and temporal temperature changes that can occur in small bodies of water are difficult to study due to the expense of buoys, floats or robotic probes. By performing acoustic tomography between shore or buoy mounted nodes, the spatial resolution of a system can be increased for little or no additional cost. As a defense application, sensor network acoustic tomography can detect the heat signatures of boats or submarines even if these water craft are equipped with sophisticated SONAR avoiding materials.

Through Research Innovation Fund we have built a five node underwater sensor network that uses sound for sensing as well as communications and ultimately perform effective micro-tomography. We are able to show a significant increase in spatial and temporal resolution as compared to sensing locally at the node locations. We also present a simple scheme that allows the tomography signal to be used for communication as well. We discuss the techniques and equipment required to build a real-world acoustic tomography sensor network to support our thesis that underwater sensor networks that use acoustic communications can greatly increase their usefulness by performing tomography in addition to local sensing.

Acoustic tomography is typically performed at large scales, up to 1000's of km. However, underwater sensor networks are usually envisioned as being deployed at very small scales, from 10's of meters to perhaps 1 km between nodes. Implementing acoustic tomography with a sensor network requires highly precise measurements of the time-of-flight for an acoustic signal traveling between two nodes. We targeted an inter-node distance range of 50 to 200 m, and thus given the inter-dependence of temperature and speed-of-sound in water, we need time measurements accurate to the order of 10's of microseconds. We discuss how to build an underwater sensor network using two recently published techniques we developed that provide sufficiently accurate timing and thus enable acoustic tomography. One of the techniques discussed does not require time synchronization across the nodes and is thus appropriate for use deep underwater.

Given a way to measure accurate time-of-flight, we then needed to design an acoustic signal that can be accurately received given a noisy channel. We present a novel application for CDMA spreading codes that allows us to quickly develop a set of orthogonal 'chirps' that can be detected over distance in the very noisy marina. These coded chirps also allow for sender identification, which allows for over-lapping multiple senders, in effect acting as a medium access control layer.

Finally we believe that sensor network research has the most impact when real-world deployments are used to test algorithms and equipment. Such deployments often provide challenges that are difficult to anticipate in the lab or simulation. In order to be viable, sensor networks must be constructed from in-expensive, easily available sensors and equipment. Therefore, using off-the-shelf components we constructed and deployed a five node underwater sensor network in a marina and used it to perform acoustic tomography. The details of our deployment and findings are published as a workshop paper at IEEE ICDCS SENS 2012 (micro-tomography implementation/ feasibility and underwater wireless sensor network physical level simulator, SeaSim2D), a journal submission to International Journal of Security and Networks (deep underwater micro-tomography algorithm), submission to IEEE OCEANS 2012 (5-node micro-tomography), and a preparation for submission to ACM WUWNET 2012 (integration of ultra-low power data communication in micro-tomography).

Summary of Continued Directions

We will continue to pursue deeper research in development of truly self-sufficient underwater wireless sensor network. In addition to innovations in time-synchronization, sensing methodology, and low-power communications, we must enable the technology by finding good ways of harvesting and/or transferring energy to the nodes.

Therefore, we intend to leverage the thermoelectric generation system that we are developing for CiSoft PTG project to build highly efficient energy harvestor suitable for underwater. The modularity and generality of the system allows easy harvesting, management, and distribution of energy even from heterogeneous sources. We will investigate several modalities including thermal, vibration, light, water flow, as well as sound. In order to match expected low level of energy input, we will design specialized acoustic signal generator that can function sufficient even in the absence of energy.

We will continue to make progress in our underwater sensor simulator to support three dimensional sensing as well as communication. Since the real system is already deployed, we will collect the realistic parameters and use them in the simulator to get a realistic result. The SeaSim tool will be used to perform a wide range of experiments with more nodes than current available 5-nodes. We will use the simulation result to guide how our sensor nodes and networks are to be built.

These ideas along with pur prior work are being prepared for presentation to a number of funding agencies including NSF and ONR.