Swarms of Autonomous Underwater Vehicles

Ulrich Kremer, October 17, 2008

The world's oceans represent over 99% of the earth's ecological space that can support life. This vast space is still widely undiscovered. Many global oceanographic phenomena are not yet well understood, in particular their impact on global warming and marine life. In recent years, autonomous underwater vehicles (AUVs) have become an indispensable tool for marine scientists to learn more about our world's oceans and large water bodies. Their use has replaced the tedious process of gathering oceanographic data through sensor probes lowered into the water from surface vessels and operated by scientists. Today's AUVs are able to gather orders of magnitude more data than the traditional approach, operating at a fraction of the overall costs, and allowing deployment under harsh environmental conditions such as those encountered during hurricanes or in polar regions.

AUVs may have a variety of different features and capabilities such as diving depths (shallow or deep water) and propulsion systems (buoyancy or propeller driven). Some vehicles are able to communicate with each other while under water through acoustic modems, and/or through short-range radios or satellite phones while at the surface. These communication features allow AUVs to coordinate their behavior in order to achieve a particular mission goal. Coordination may be in terms of resource sharing, or synchronized motion and swarming patterns.

The main thrust in the design of autonomous underwater vehicles such as the Slocum glider [2, 3] has been the development of a reliable, effective, and low cost data-acquisition instrument, typically for a small collection of sensors to measure water salinity, pressure, and temperature. We are in the process of developing a new glider programming architecture for the Slocum AUV that consists of a new domain-specific language, compiler, runtime system, and hardware platform. The gliders will also be equipped with acoustic modems allowing underwater glider communication within a 5-10km range [1]. The enhanced glider architecture enables the deployment of a variety of new sensors, allows on-board data processing and decision making, and supports coordinated swarming behavior through underwater and surface communication.

Swarming patterns include search and tracking behaviors. A search behavior involves AUVs that sweep over a particular physical search area in a synchronized fashion. Communication is used to exchange and adjust glider positions during the search. Tracking behaviors are useful to observe and follow dynamically developing oceanographic phenomena such as algae plumes or drifting toxic material and pollutants. Swarming allows gliders to produce a three-dimensional view of the tracked phenomenon, and stay with the phenomenon as it develops and interacts with its marine environment. New swarming behaviors may be triggered if secondary, interesting physical phenomena occur. This may involve splitting the swarm into two groups, one that continues the original tracking task while the other group tracks the new phenomenon.

We believe that swarming patterns are important for many cyber-physical systems. They include lining up aircraft during their final landing approach, moving traffic through synchronized traffic lights in urban environments, or ensuring a minimal distance between two vehicles on a road or two trains on a track. Swarming behaviors may be entirely distributed, requiring the involved actors to coordinate their behaviors autonomously, i.e., without the help of a remote control center or decision maker. Other behaviors may allow intermittent contact with a control center. For instance, gliders may surface every three hours and communicate via a satellite connection (e.g.: Iridium phone) while acting autonomously as a coordinated group under water. *The effective specification and implementation of swarming behaviors is an important problem for cyber-physical systems.*

Currently, we are in the process of installing acoustic communication modules in up to four Slocum gliders funded by an NSF MRI grant. A Slocum glider equipped with our new programming architecture has been deployed in the Atlantic Ocean, approximately 30km off the shore of New Jersey. The glider was able to successfully track a thermocline. A thermocline is a thin layer of water (2-3 meters) that separates the warm surface water from the much cooler deep sea water. Thermoclines typically form over parts of the continental shelf during the summer months. This experiment showed that individual gliders are able to react to sensor readings under water which is a behavior that the original programming architecture of the Slocum glider was not able to support. The ability to react to events (e.g.: sensor readings or communication) while under water is a key feature needed to implement autonomous swarming behavior.

References

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Short Bio

Ulrich Kremer is an Associate Professor in the Department of Computer Science at Rutgers University. He received his PhD and MS in computer science from Rice University in 1995 and 1993, respectively, under the supervision of Ken Kennedy. His research interests include programming environments and advanced optimizing compilers for imperative (Fortran, C), object oriented (Java), and parallel languages (HPF). He has investigated compiler-directed techniques to reduce the power dissipation and energy consumption of programs, in particular reductions in CPU and disk power/energy. More recently, he has worked on new programming abstractions and compiler optimizations for location-aware and resource-aware applications, including autonomous underwater vehicles and hybrid networks of mobile and stationary devices. Ulrich has received an NSF CAREER award to support his low power/energy compiler work. In addition, he has been the PI and Co-PI of several other projects funded by NSF or DARPA.