LOW-COST UUVs FOR
TASK SPECIFIC AND EXPENDABLE MISSIONS

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Abstract

Low-cost UUVs are beginning to perform useful missions in the ocean. We present the capabilities of Nekton Research's Ranger MicroUUV and then describe some of the current and future missions being considered for this new class of vehicle. These include: Near-surface oceanography, routine water quality assessments, broadband toxicity sensing, event triggered deployments, and missions where the UUV is considered expendable.

INTRODUCTION

To date, nobody has lost a UUV, or at least permanently lost a vehicle. This means that the operators of UUVs are either very good at what they do, lucky, or are conducting only conservative missions without much risk. It is probably a combination of all of these but since there are many important discoveries still to be made in the ocean, the risk of loosing a UUV should not outweigh the potential gains. This is of course an economic decision since before anybody will risk loosing a million dollar UUV, they'll have to be convinced an amazing discovery awaits a successful recovery. One of the points of this paper is to begin identifying important missions that can be accomplished using a $50k UUV, the loss of which would not ruin the career of whoever was deemed responsible.

Much early UUV design focused primarily on vehicle versatility. However, versatility incurs certain costs in the form of redundant components and added payload. Today there is a mounting need for low-cost, single-task vehicles able to perform such operations as routine monitoring and mine neutralization. Nekton Research's Ranger UUV is a low-cost system that is designed to be simple and reliable. An example of how economies of scale can reduce the price of UUVs is the case of the Navy's Mk39 expendable sonar training target. Over 14,000 Mk39s have been produced by Sippican, and for bulk orders, the Navy pays less than $4000 each. [1,2] While these 0.12 m diameter, 1 m long vehicles have been used for other missions with some success, [3] their 2 knot minimum speed, short duration battery pack and the erratic control that results from their "bang-bang" solenoid control surface actuators limit their use for many applications.

Figure 1: Nekton's Ranger MicroUUV

Since UUVs are useless without sensors, we've assembled a list of sensors (Table 1) that have, or will soon be used on Ranger.

Table 1: Sensors available for Ranger

Depth	Optical backscatter
Temperature	CDOM
Conductivity	PAR
pH	Radiation
Dissolved Oxygen	Trace metals
Chlorophyll	TNT
Ammonia	Sidescan Sonar

UUVs for Near-Surface Oceanography

A thorough knowledge of the chemical and thermal flux at the sea-air boundary is necessary for understanding climate and CO_2 cycling. Unfortunately, there are gaps in our knowledge of this critical boundary. For example, while this boundary is well studied during fair weather, much of the flux across the sea-air boundary happens during large storms when all of the research vessels are safely in port. This is a dynamic place and though the surface of the ocean is easily studied from space when there are no clouds, the water column down to about 10 meters can be a difficult place to work. Ship-generated noise and motion complicate ship-based measurements, and while UUVs can avoid this, operators are wary of collisions with surface craft and therefore rarely program their vehicles to get within 5 meters of the surface. Drifting sensors and gliders make frequent trips all the way to the surface though since they must maintain accurate, un-fouled sensors for a very long duration (>6 months), they usually avoid drawing near-surface water into their sensors because contaminants are concentrated at the sea-air boundary. Small, LCUUVs are useful for near-surface oceanography because:

1. Small size and low-inertia relative to the motions and forces of surface waves allow more accurate tracking of discrete volumes of water.
2. Small size is less of a danger to surface craft. (Lawyers will remind us this is more important than any damage a surface craft does to a scientific instrument)
3. In the unlikely event of a collision and vehicle loss, the financial cost is relatively small
4. Multi-vehicle arrays can be used to increase spatial and temporal resolution

These attributes are useful for the following applications:

Mapping Thin Layers with a UUV

In coastal ocean waters, phytoplankton aggregate in semi-stable thin layers that scatter sound & light. These layers typically form in hours or days & can be 10cm to 1m thick & 1-10 km wide. Current theories fail to explain rapid thin layer formation & dissolution. Higher resolution spatial & temporal data is required before substantial progress can be made. Thin layers interfere with acoustic & optical measurements for both oceanographic and Navy purposes, e.g., by creating false bottom signals or concealing targets from surface sonar.

Maturing micro-UUVs have recently demonstrated capabilities similar to those required for mapping the spatial extent of a feature on the order of 1m x 1km. A new ammonia sensor under development by SubChem and WET Labs could be combined with a micro-UUV to enable low-cost 3D mapping of thin layers. Upon detection of thin layer formation, one or more micro-UUVs could be deployed from an aircraft, a large AUV, or from a docking station installed at an ocean observatory or vertical profiler. The micro-UUV could fly out and map the spatial extent of the layer as it matures..

Routine Water Quality Monitoring

For most institutions responsible for monitoring water quality, it is very expensive to send a team out on the water to take critical measurements. The result is that fewer measurements are taken less often at a time when population, pollution and terrorist threats are causing concern for the quality of the water we drink and recreate in.

All of the common parameters of water quality can be measured with the sensors listed in Table 1, so Nekton Research is starting to use the Ranger for routine monitoring of reservoirs without the use of a boat. The dissolved oxygen, chlorophyll and temperature can easily be measured as a function of depth using a shore launched UUV. The path of the UUV is preprogrammed to take measurements not only at legacy locations where measurements were collected from a boat, but also between the stations. The vehicle navigates using GPS and follows a saw-tooth dive profile between surface fixes. If needed, an on-board syringe type water sampler could capture water samples for laboratory analysis. The sampler could either be triggered by anomalous sensor readings, e.g. low DO, or at pre-programmed locations.

Broadband Toxicity Sensing

Early detection of harmful compounds in aquatic environments is essential to the protection of drinking water sources, recreational environments and marine fisheries. Despite significant technological advancements in spectrometers and MEMS micro-sensors, real-time broadband detection of known and unknown toxins using small, inexpensive devices is years away. In the interim, Biological Early Warning Systems (BEWS) offer the greatest potential for a real-time alarm to signal the presence of harmful toxicants in aquatic environments. Nekton Research is currently developing an aquatic BEWS that can be deployed on Ranger.

Whole organisms (sentinels) are the oldest type of BEWS e.g., canaries for gas detection in coal mines.

[4] The behavioral response of the organism is the basis for detecting and estimating severity of irritants in the water. Sentinels possess the inherent advantage of presenting a complete physiology, with all of the processes & pathways, as a target for any contaminant; they also dodge native water sample issues associated with cell & molecular biosensors (e.g., clogging).

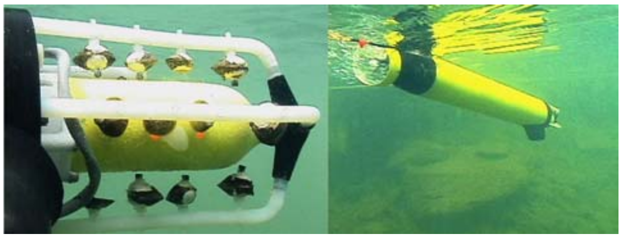

Figure 2: Clam-based broadband Toxicity Sensor mounted to the nose of Ranger

Clams and mussels are known to close their shells in response to irritants. [5] The gaping behavior of clams and mussels is not entirely understood but appears clearly to be a reaction to irritants [5], and, the gape is easily measured [6].

Nekton is working on an Army sponsored program to develop and demonstrate clam-based BEWS for Ranger. Sensors measure the gape of each of up to 16 clams to determine if the clam is feeding or whether it has "clammed up". When many clams close, the on-board computer scans the temperature, dissolved oxygen and chlorophyll levels to see if a drop in one or more of these readings could explain the behavior. If this sensor fusion fails to explain why the clams have closed up, a water sample is taken, the position noted and the vehicle swims back to its recovery point where the water sample can be analyzed. We plan to deploy this mobile, broadband toxicity sensor in large drinking water reservoirs in the near future.

Event Driven Deployments

Continuous, long-term measurements in the ocean are the only way to understand gradual changes and capture episodic events such as harmful algal blooms (HAB), tsunamis or the formation of new deep-sea vents. Current ocean observatories like MBARI's MOOS, Rutgers's LEO-15 or University of Maine's GOMOOS are demonstrating that long term sensing in the ocean is possible. Future initiatives like NEPTUNE and NSF's ORION programs are ensuring there will be ample opportunities to take continuous, long-term measurements in the future. One of the most exciting prospects of ocean observatories will be to capture periodic events. Unfortunately, observatories are fixed and only sparsely populate a given area and as such are not able to quantify the spatial extents of small-scale events around the observatory. Furthermore, surface and mid-water measurements are taken from moored systems and the movements and noise from the mooring itself can taint measurements. What is needed is a system that can be immediately deployed into the water around an observatory on a routine basis or when an important event is detected. It is envisioned that AUVs will be stationed at observatories for just this purpose and all of the artistic renderings of future observatories include a small yellow AUV patrolling around the observatory. While this may be a reality someday, there is at least one problem to surmount. While docking systems for AUVs have been demonstrated many times, the long-term reliability in the ocean will not be 100% and a failure will probably result in the loss of the AUV. Since most AUVs cost at least $250k, the loss of even one vehicle is unacceptable. The solution is to mitigate this risk and use a LCUUV.

An alternative to launching an AUV from an observatory for event-driven deployments is to air-drop AUVs. For example, when an earthquake is detected along the Juan de Fuca Ridge in an area where a new thermal vent may have been initiated, one of the Navy's P-3 Orions based at Whidbey Island could be deployed within hours and air-drop one or more microUUVs that could search for the sources of new thermal plumes. Mapping surface events like HABs or Thin-Layer formation may be more feasible in near term, but the desire to collect some water from a freshly initiated thermal vent has prompted at least one group of researchers to consider aerial deployments of MicroUUVs.

Expendable Deployments

Nekton Research is using its Ranger MicroUUV to demonstrate that a low-cost swimming UUV can self-navigate within an LBL acoustic navigation network and use its sonar to zero-in and impact a mine-like target. This is the first step in the development of an expendable, homing torpedo for mine neutralization that is based on a UUV. This concept is especially attractive since many modern mines are extremely sensitive and can be triggered by the presence of even a small vehicle. If this happens, the operators would be happy they didn't loose a valuable Navy mine hunting vehicle

We have integrated an Imagenex mechanical-scanning sonar into one of our existing Ranger Micro UUVs

(Figure 1) and have begun to use it to reacquire and navigate to a mine-like target. Acoustic navigation and interoperability with existing Navy systems will be demonstrated by navigating Ranger in a two-transponder baseline array and using Ranger's MicroModem to navigate and communicate with nearby vehicles and to the surface.

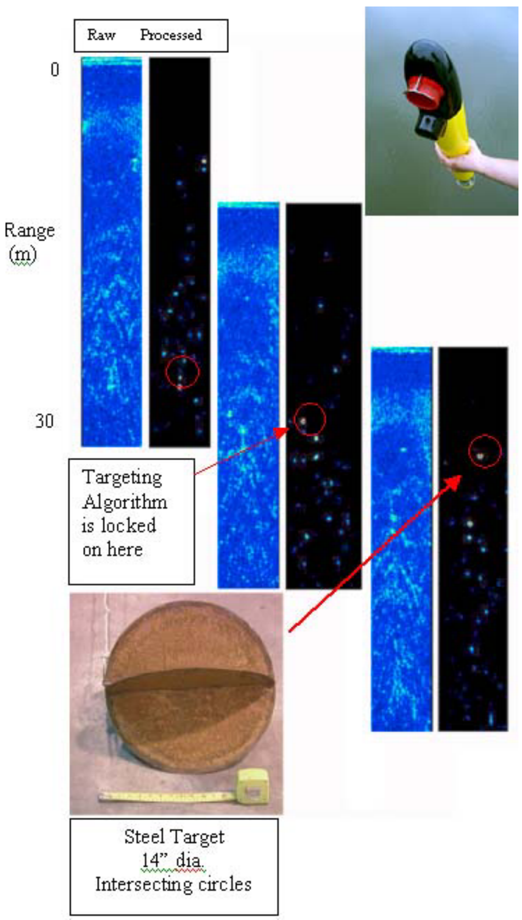

Figure 3: Time series of Ranger's sonar showing the acquisition and homing towards the target shown.

Conclusion

Low-cost UUVs are available today and as the Navy's comfort level increases in using LCUUVs for a growing variety of missions, vehicle demand and costs will be reduced even more. At the same time, an increasing variety of sensors are becoming available that are small, low-power and inexpensive. Such innovations guarantee an even greater number of opportunities for LCUUVs in the future. Soon, schools of LCUUVs may be working collaboratively to locate chemical plume sources, accurately map small-scale fronts and turbulence structures and dynamically map the thickness and extents of thin layers.

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