Development of a Biological Sensor Bay for the Ranger AUV

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Abstract - Nekton Research is developing a biological sensor bay (BioBay) for use on the Ranger AUV. Transporting living biosensors on an AUV opens up new opportunities for environmental monitoring. Biological sensors provide an indication of overall water quality because organisms react to a broad variety of different pollutants. Measuring the extent to which a clam is open or closed (gape) has been shown to correlate with the presence of pollutants in the water.[1] In order to account for intra-population statistical fluctuations, BioBay is capable of transporting 16 clams, each with a dedicated gape sensor.

Through this design and research effort we have created several BioBay prototypes and assessed their impact on Ranger's performance. Clam gape sensing circuitry has been designed and integrated with Ranger's data logging capabilities. Open water field tests have been conducted with BioBays mounted on Ranger.

Results from the BioBay design project are discussed in this report along with descriptions of the designs and details about test procedures.

Introduction and Background Information:

This research and development effort has been carried out as a Phase I SBIR under the auspices of the U.S. Army Center for Environmental Health Research. The goal of this project was to design and build an external payload bay for carrying a Sentinel Bivalve Biological Early Warning System (BioBay). The prototype BioBay has been designed to be carried by Nekton's Ranger AUV. By implementing BioBay on Ranger, we have explored the feasibility of carrying a Biosensor on a small AUV. The performance of the Ranger AUV has been evaluated before and after the addition of BioBay. The main concerns we have addressed are:

1.) Does BioBay hinder vehicle speed, stability, or handling performance?
2.) Will the clams be exposed to uniform flow, and is the water passing over them representative of the water that the vehicle is driving through at the same instant?
3.) Can clam gape be accurately sensed in BioBay?

A wide range of work has been done using whole organism bio-sentinels. Whole organisms are able to detect a wide variety of pollutants, many of which are toxic to humans. Dr. Joel Allen, formerly at the University of North Texas and now with U.S. EPA, has been working with bivalve biosensors. The designs that we have developed for this mobile effort are similar to the designs used by Dr. Allen.

Progress to Date:

1.) <u>Evaluated Technologies for Sensing Clam Gape:</u>

In order to extract information from a Bio-sentinel, one has to be able to sense its behavior. Clam behavior generally involves a shell open - shell shut response to a stimulant. The shell is hinged in one place, so the open condition and shut condition is easy to identify. Past work in this area used inductive proximity sensors to sense when the clam was open or shut. For this effort, we evaluated several sensing technologies and settled on using magnets and Hall Effect sensors. Hall Effect sensors are very small, inexpensive, and easy to waterproof. They provide a well defined 5V-0V transition when placed in the immediate vicinity of a strong magnetic field. This signal change is easy to interpret with a microprocessor. A magnet is glued to the top half of the clam's shell which moves with respect to the Hall Effect sensor. As the magnet/clam shell moves, the magnetic field varies causing the Hall Effect sensor to transition in and out of saturation.

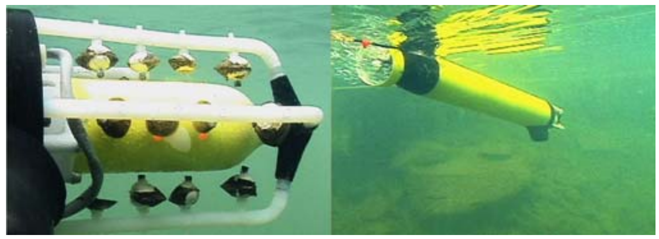

Figure 1: Ranger AUV with the nose mounted clam-based biosensor.

2.) <u>Designed, Fabricated and Tested Clam Sensing Circuitry:</u>

Once the Hall Effect sensors had been identified, a circuit board was designed to interpret signals from 16 Hall Effect sensors. The circuit board has 16 analog to digital inputs. This was done so analog clam gape sensors could be used later if needed. The sensor board reads the signals from the Hall Effect sensors and outputs an RS-232 data stream which is interpreted and logged by the processor onboard Ranger. A custom circuit board was designed and fabricated for this application.

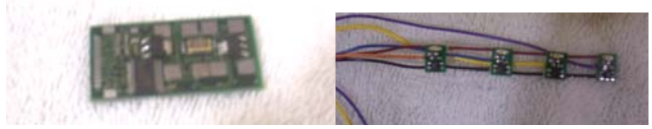

Figure 2: Main sensor board and Hall Effect sensor assembly

Once the board was designed and fabricated, software was written to log the clam gape data onto Ranger. The sensor board was assembled into BioBay and tested in the shop. After some modifications were made to the sensor board, BioBay was tested in open water. The sensor board is capable of reading 16 analog channels for future clam sensing work.

3.) <u>Designed Three BioBay Configurations:</u>

Nekton's Ranger AUV is a 5kg, 36" long 3.5"Ø AUV, so sensor payloads must be small, and preferably neutrally buoyant. Minimizing drag on the Ranger platform is a key issue as well. Each design housed multiple clams and clam sensors. It also allowed for a YSI, conductivity and temperature sensor to be carried. Three BioBay concepts were created.

The first design is the nose mounted BioBay. Clams are arranged in four rows of four clams that surround the sensor board pressure vessel in the center of the vehicle. This design was fabricated and developed into a working prototype. It is a compact design that is easy to integrate onto the vehicle, does not increase the vehicle's frontal area, and allows space for several YSI sensors.

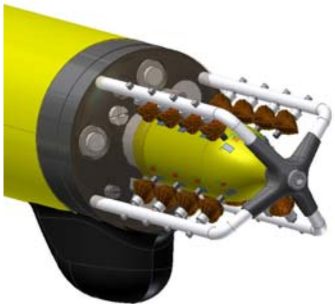

Figure 3: Nose Mounted BioBay

The next design had clams located in pods that hung below the vehicle. The main sensor board was located in a pressure vessel underneath a flow form on the front of the vehicle. The advantage of this design was that it allowed more room to carry additional YSI sensors on Ranger. The drawback was that it significantly increased the frontal area of the vehicle and greatly increased the drag of the vehicle.

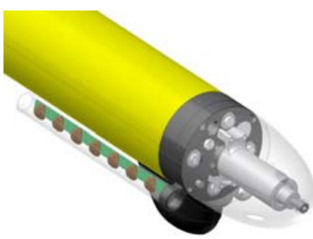

Figure 4: Clam Pod BioBay

The third design was created after the first design had been developed into a working prototype. Therefore, this design took into account the lessons learned from the previous two. The design is a low drag shape that allows water to flow in over the top of the clams. The disadvantage of this design is that it holds a maximum of eight clams. A nose shape similar to this was flow tested to determine drag, but a working prototype was not developed under the Phase I contract.

Figure 5: Low Drag Biobay

4.) <u>Fabricating BioBays:</u>

The nose mounted BioBay was designed to have the sensor board pressure vessel mounted to the center of the front end cap. The outside wall of the pressure vessel is lined with four rows of four Hall Effect sensor boards. The Hall Effect sensor boards are then epoxied to the pressure vessel. This entire unit is submerged in a mold that contains syntactic foam. The foam flows in and around the pressure vessel and the Hall Effect sensor boards, encapsulating everything in water tight insulation.

The mold shapes the syntactic foam into a hydrodynamic flow form. This unit is surrounded by four posts that wrap around and meet at the front of the vehicle.

An elbow fitting allows the power and RS-232 communication wires to go back into the main vehicle without going through a connector.

Clams are mounted to BioBay by super gluing a nylon screw to the bottom half of their shell. The screw threads into one of the four posts. The entire BioBay unit then attaches to the front of Ranger. The BioBay is a modular sensor payload, which can be easily removed and replaced with another payload.

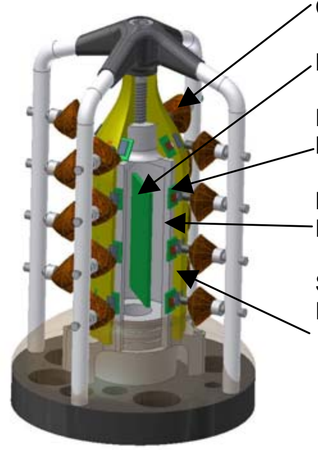

Figure 6: BioBay Assembly

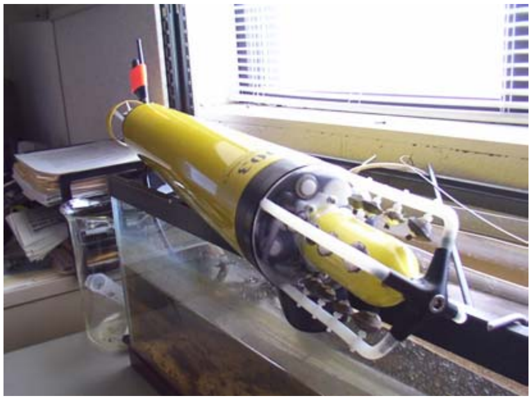

Figure 7: Finished Biobay Installed on Ranger

5.) <u>Flow Tank Testing:</u>

One of the goals of this project was to determine what effect the Biobay had on the performance of the Ranger AUV. In order to do this, the Ranger AUV was mounted in Nekton's flow tank. A baseline coefficient of drag was determined by running the standard Ranger nose shape at different flow speeds and looking at the force produced on the six-axis load cell. The coefficient of drag for the BioBay Ranger is 90% greater than the coefficient of drag for the standard nose configuration. The Phase I BioBay effort is a proof of concept, but in the future, this will have to be addressed. This increase in coefficient of drag will greatly decrease mission duration.

Figure 8: Ranger mockup mounted on six-axis loadcell in flow tank test section

Flow visualization was also used to make sure each clam received adequate flow. For this test, 16 unoccupied clam shells were installed in the BioBay. BioBay was installed on Ranger, and Ranger was installed in the flow tank. Blue dye was used to make sure that water was passing by each of the clam positions.

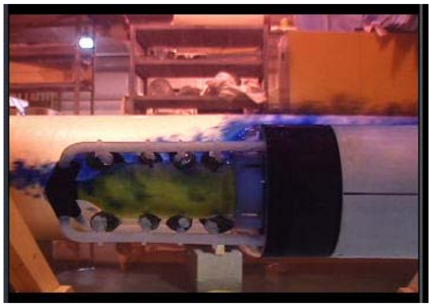

Figure 9: Flow visualization around the BioBay

6.) <u>Testing Biobay with Live Clams:</u>

The first clam test involved installing one live clam on BioBay and testing it in a beaker of fresh water. The clams used for this study are *Corbicula fluminea*. These clams are a widespread introduced species that are easy to find and easy to keep alive. We used *C. fluminea* where it was already present. Clams were installed on BioBay by gluing a nylon screw to the bottom half of their shell. The screw threaded into one of the four posts that surrounded the main sensor board pressure vessel. A magnet was glued to the top half of the clam shell. The screw and the magnet were glued to the clam using a jig to hold the screw and the magnet in radial alignment with each other. This allowed the clam to thread in and out on the post without varying the strength of the magnetic field radially. Screwing the clam in and out adjusts the magnet's distance from the Hall Effect sensor, and allows the open/shut threshold to be set. The screw and magnet were glued to the clam using high strength super glue that cures underwater. This allowed the clam, the screw and the magnet to be loaded into the jig, apply the glue, and then place the entire jig back in the water to minimize the length of time the clam is out of the water.

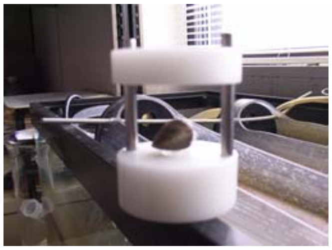

Figure 10: Jig for gluing screws and magnets to clams

BioBay was placed in a beaker of fresh water with the main sensor board powered up. The open/shut threshold for the clam was adjusted by rotating the clam to the necessary position. The Hall Effect sensor boards that are embedded on the outside of the main sensor board pressure vessel also have LEDs that light up when the clam opens. This allows the user to easily adjust the open/shut threshold without the main sensor board sending data to HyperTerminal. The live clam was observed as it opened and started siphoning water. The main sensor board registered an open condition. A syringe of saline was then discharged near the clam to simulate swimming through a region of contaminated water. The clam closed its shell; the main sensor board registered a closed condition. This validated that BioBay worked in a controlled environment, and that the Hall Effect sensors and magnets had been matched correctly.

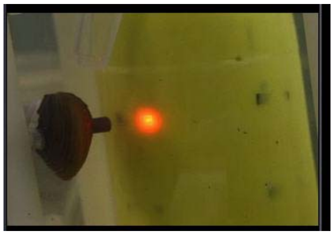

Figure 11: Initial test of BioBay with a live clam

7.) **<u>Testing BioBay in Open Water:</u>**

The first open water test for BioBay was to make sure that the vehicle could still be controlled. Increasing the vehicle's coefficient of drag by adding drag to the front of the vehicle could bring the center of pressure so far forward that the vehicle's controllers could no longer keep it flying in a stable condition for a given speed. Fortunately, this was not the case. The pitch and yaw controllers worked flawlessly even with the increased drag.

After the vehicle passed this test, three of the unoccupied clams were removed and replaced with live clams. Ranger was run in this configuration while recording clam open/shut, conductivity, temperature, depth, GPS position and elapsed mission run time.

Figure 12: Open water testing. Clams are siphoning with mantle extended; LEDs are on

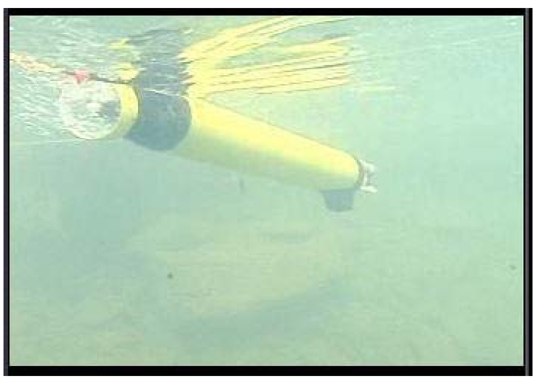

Figure 13: Ranger initiating a dive with BioBay

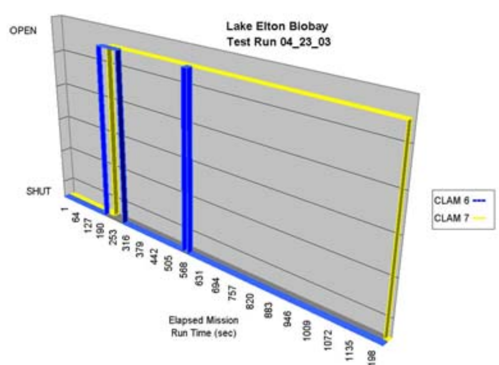

Figure 14: Clam open/shut data recorded during the Lake Elton mission

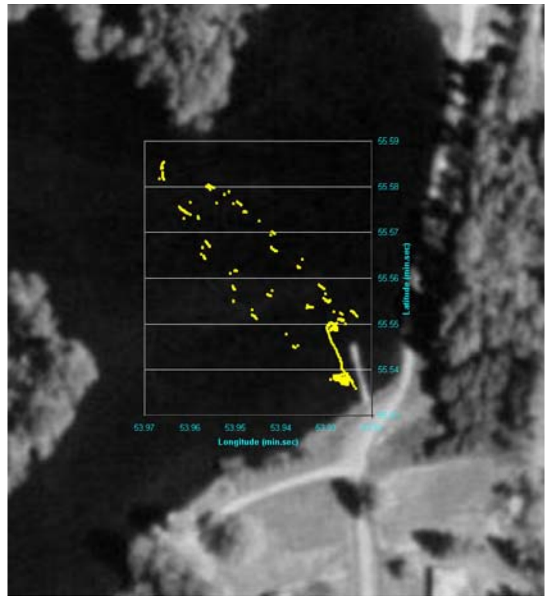

Figure 15: GPS position fixes while Ranger runs out and back away from the pier on Lake Elton. Ranger was launched and retrieved from the pier

Conclusions:

The Phase I BioBay design has worked well enough that we would like to develop it further. We were able to log clam gape data on Ranger while operating the vehicle in an open water environment. Ranger is able to swim in a controlled fashion even with the increase in drag. It's definitely possible to operate this sensor on Ranger. We hope to learn exactly what the clams can tell us, and what other Biosensors we can integrate in future work.

Proposed Future Efforts:

Nekton has submitted a Phase II proposal for funding to continue development of the BioBay. Under Phase II, we would like to characterize the conditions that cause clams to respond to irritants other than water-borne toxins. We are concerned about flow velocity, temperature and depth changes, and vibration and acceleration experienced by the clams while enroute on Ranger. We would also like to evaluate concentration levels that evoke a repeatable response from the clams. We also wish to pursue other biosensor technologies. We are looking for biosensors that fulfill the following criteria:.

1.) Detect broadband water-borne toxins
2.) Fit on Ranger (nominally 3.5"Ø x 7" length maximum)
3.) Do not degrade Ranger's performance any more than the Phase I design
4.) Have a response time of 1-2 seconds or less
5.) Be able to reset to a "no toxins present" state
6.) Be field transportable by one person
7.) Require very little support equipment
8.) Introduce no harmful chemicals or organisms into the areas where they do not already occur

We are interested in variety of different manifestations such as cell based, tissue based, or whole organism based. If they meet the criteria, or come close to meeting them, we would appreciate you contacting us.

Another area we would like to investigate is statistical sensor fusion to validate or dismiss the data coming from the clams or other biosensor. Ranger has the ability to carry a suite of water quality sensors in addition to BioBay. These sensors can be monitored to see if they reporting similar conditions as the clams. This data can be statistically processed in near real time to aid in interpreting the data from the biosensor. We foresee several areas where a Biosensor-equipped Ranger may be useful. One is monitoring water quality and early pre-intake detection of contaminants in drinking water sources for forward deployed troops; another is monitoring reservoirs for homeland security.

Acknowledgements:

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References:

[1} Allen, HJ, KL Dickson, H Martin, KA Thesen and WT Waller. 2002. Monitoring Watersheds: Biomonitors and Other Measures.