Cybermussels: A Biological Sensor Network using Freshwater Mussels

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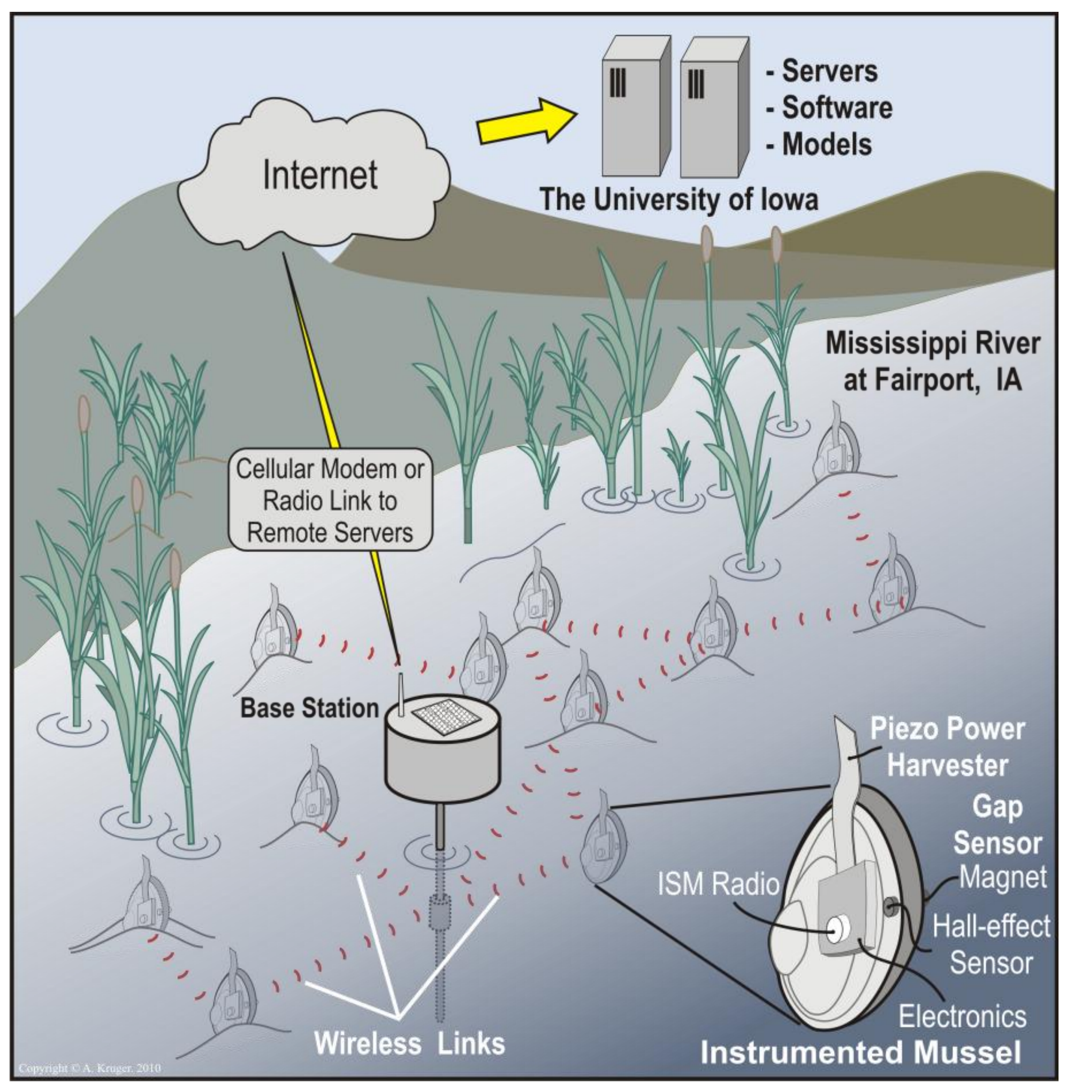
ABSTRACT

Native freshwater mussels are a guild of long-lived, suspension feeding bivalves that can influence nutrient cycling by transferring nutrients from the water column to the riverbed. There is a long history of monitoring the response of individual mussels to changes in their environment. These range from biological investigations of mussels to complete commercial systems that use mussels as biological sensors, such as *Mosselmonitor* [1]. Our work goes beyond this previous literature in networking individual mussel sensors to create a wireless biosensor network. The gape, a rhythmic opening and closing of a mussel's valve, is by far the most commonly studied/used behavior, however we are exploring sensors for three additional variables: heart rate, valve pumping, and burrowing.

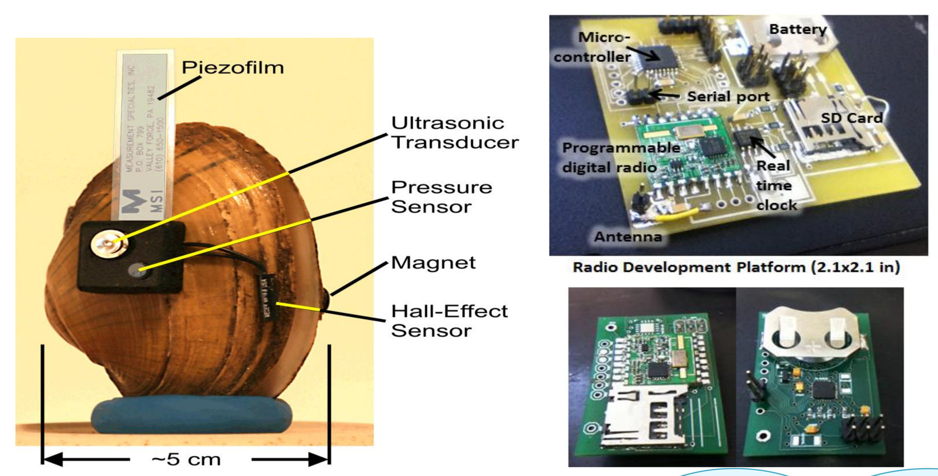
PROJECT GOAL

Our long-term goal is to build a prototype mussel-based biosensory network located in the Mississippi River near The University of Iowa's Lucille A. Carver Mississippi Riverside Environmental Research Station (LACMRERS). Servers at IIHR-Hydroscience and Engineering at The University of Iowa main campus, located about 50 miles away, will ingest the super-organism data along with other relevant water quality data. Computer models on these servers will integrate and transform the data as a means to further our understanding of nitrogen dynamics as recorded by a living, biosensing network of mussels.



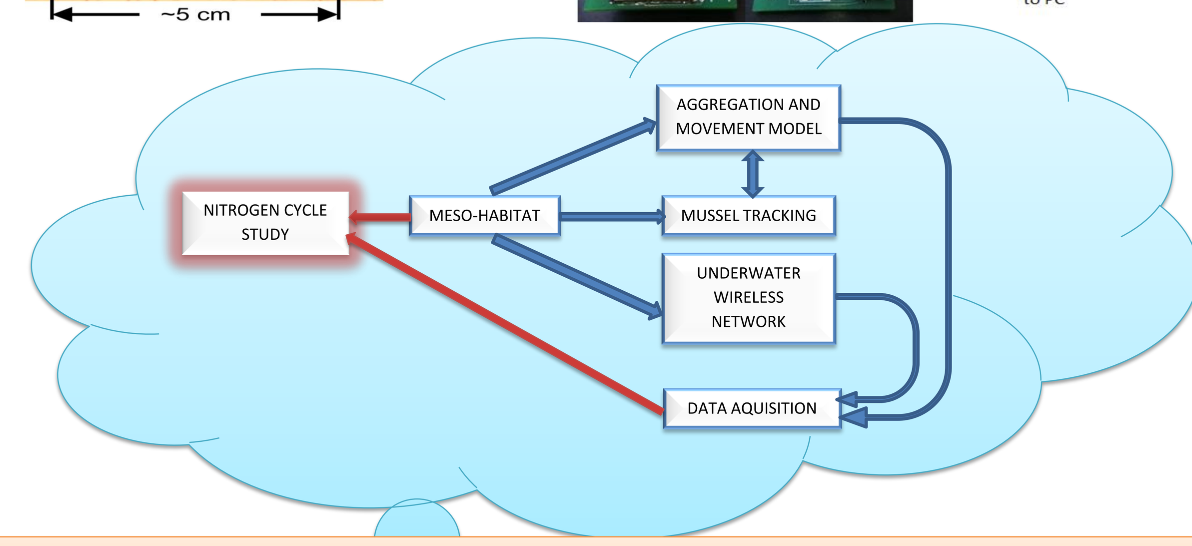
WIRELESS NETWORK

We have designed simple, compact "backpacks" to be glued to the mussels; these backpacks include a Hall-effect sensor to monitor the gape response of the mussel, memory, and a low-power wireless transceiver to connect the mussels into a wireless sensor network. It is well-known that RF wireless signals suffer very high attenuation underwater and therefore it has been assumed that underwater wireless networks are not feasible. However, we take advantage of the fact that freshwater mussels tend to congregate together in closely-packed clusters, and our preliminary experimental work has shown that off-the-shelf wireless transceivers work quite well underwater over distances of up to 1.2 meters (~4 feet).



Fully customizable micro-radio transceiver module

- Low Power
  - Microampere-range sleep mode
  - 18.5 mA min. rx
  - Up to +20 dBm tx (@ 85 mA min.)
- Customizable
  - Fully programmable controller with 32K of SDRAM
  - Inputs for 10+ sensors
  - Programmable digital radio capable of FSK, OOK, and GFSK modulations.
- Rich Feature Set
  - RSSI detector
  - Temperature sensor
  - 1 8-bit ADC, 1 10-bit ADC
  - Removable SD card, with switchable power supply
  - Real-time clock with alarm
  - Two-way debug communication to PC



AGGREGATION AND MOVEMENT MODEL

We model the behavior of freshwater mussels as follows;

1.The mussels, in a bid to prevent dislodgment and minimize predation, aggregate together in clusters. We assume that each mussel '*i*' is aware of its conspecific neighbors and as such move towards a local cluster center by the following equations;

I. $$\alpha_i = \sum_{j=1}^{N} \frac{P_j - P_i}{(\|P_i - P_j\| + 1)^n}$$

II. $$\Delta_{1,i} = \beta_{1,i} \frac{\alpha_i}{\|\alpha_i\|}$$

where $P_i = (x_i, y_i, z_i)$ is the location of mussel i and $\beta_{1,i}$ is a scaling parameter.

2.The phytoplankton and other food resources for the mussel in the local environment, γ, obey the general population growth model given by

I. $$\dot{\gamma} = (a - b - c)\gamma + v$$

where *a, b, c* and *v* are growth, mortality, mussel ingestion and advection coefficients.

3. The freshwater mussels also react to scarcity of food resource which is determined by the mussel density in a cluster or local proximity to other mussels. We model this using the formulation;

I. $$\Delta_{2,i} = -\beta_{2,i} \sum_{j=1}^{N} K\,\gamma(P_j) \frac{P_j - P_i}{\|P_i - P_j\| + 1}$$

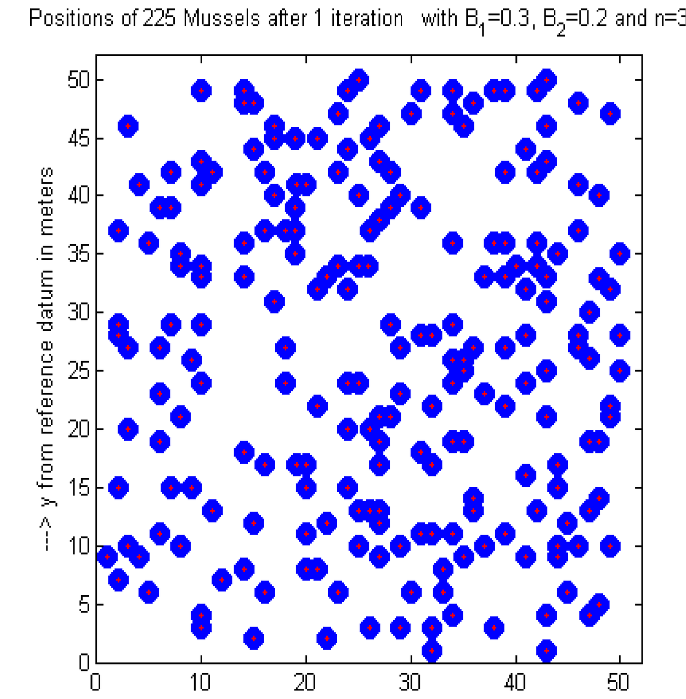
where $\beta_{2,i}$ and K are scaling parameters.

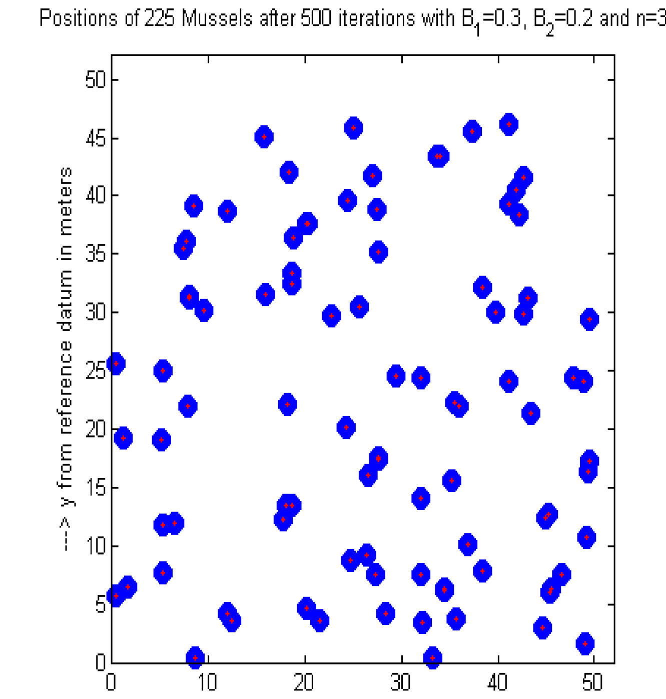
4. Combining 1-3, the motion made by a mussel i at time t is then given by;

I. $$P_{i,t} = P_{i,t-1} + \beta_{3,i} \frac{\Delta_{1,i} + \Delta_{2,i}}{\|\Delta_{1,i} + \Delta_{2,i}\| + 1}$$

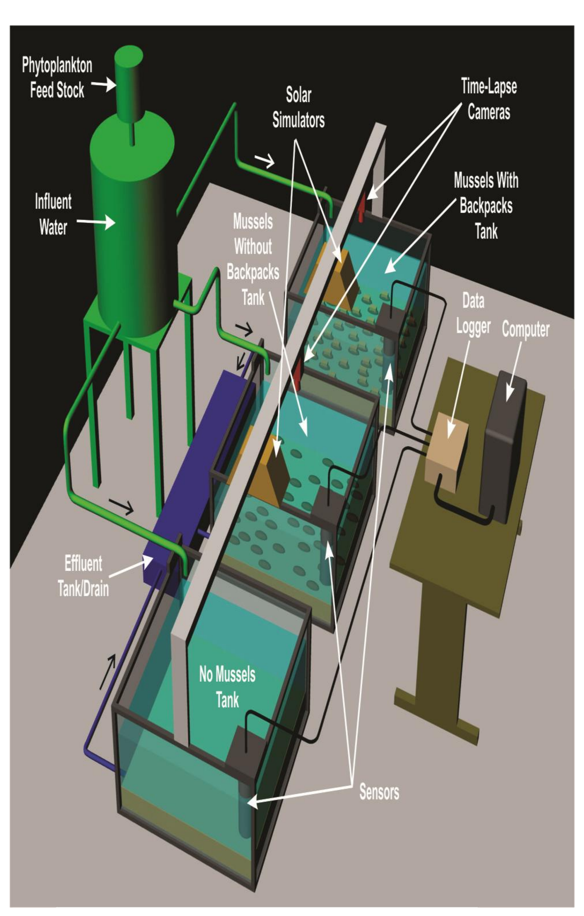
II. $$\beta_{3,i} \sim U(0, 0.3)$$

A sample simulation of our model is shown with initial and final mussel distribution after 500 iterations. Work is still ongoing to fine tune the model



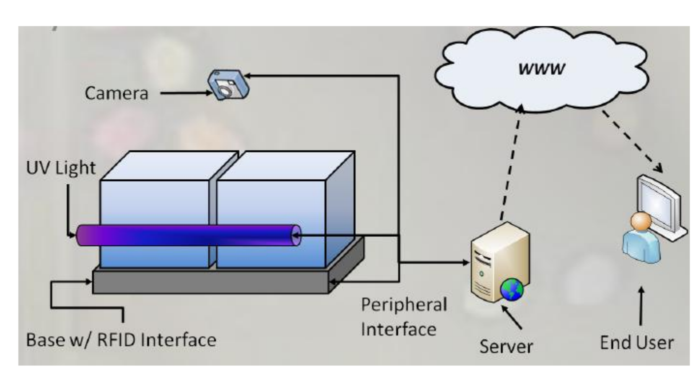


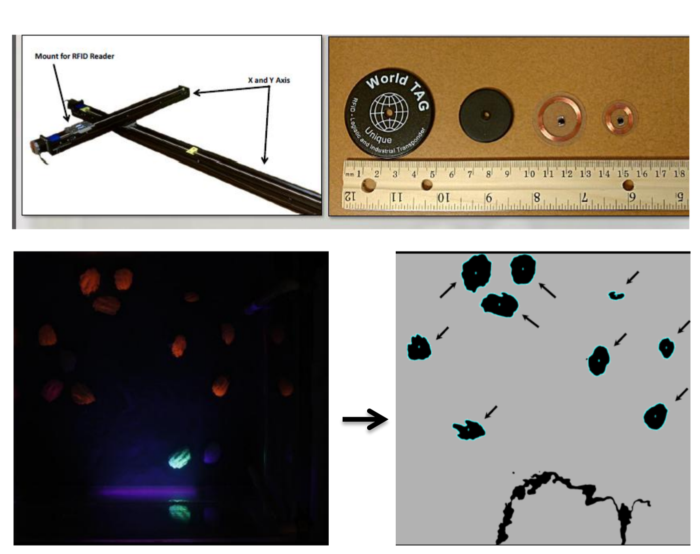
MESOHABITAT



The mussel meso-habitat consisting of three chambers, each equipped with sensors that monitor water quality including turbidity and nitrate levels. The control or reference environment tank has no mussels. In the second tank one group of mussels are free range, and in the third tank the mussels have backpacks.

TRACKING MECHANISM





Tracking system used to track the mussels in our experimental mesohabitat consisting of a high resolution camera controlled through custom computer application. Continuously acquired pictures of the tanks are processed to identify and location each mussel. In addition, the system utilizes RFID tracking to detect and log unique mussel locations. Both processed images and RFID data are stored in a central database to be made available online together with time-lapse videos.

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