Design and Development of the Sharkduino Animal Tag System

William Laney *REU program, College of William and Mary*
Dr. Wouter Deconinck *College of William and Mary, Physics Dept.*
Dr. Kevin Weng *Virginia Institute of Marine Science, Fisheries Science Dept.*

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Abstract

Many pieces of information about the movement and habits of marine animals are currently unknown. This information can be found for terrestrial animals through direct observation or video surveillance; however, these optical methods are not effective in aquatic environments. To circumvent this problem, researchers "tag" aquatic animals with small sensor systems that record data about the animals movements. The researchers then recover the tag and use signal analysis to draw conclusions about the habits of the animal. Unfortunately, commercially available tags are expensive and single use. We created a cheap and reusable tag, used on sandbar sharks held in captivity at the Virginia Institute of Marine Science (VIMS) Eastern Shore Lab (ESL). The tag consists of a three-axis accelerometer and three-axis gyroscope for movement information as well as a real time clock (RTC) for timing. The data is written to micro SD card. This is all run through a 3.3V Arduino Pro Mini microcontroller, and powered by a lithium ion polymer (LiPo) battery. Initial prototypes were built using commercially available components connected through point-to-point wired connections. While creating the prototype, size, form factor, and power consumption were serious concerns. Once it was confirmed that these prototypes functioned as expected, we created custom printed circuit boards (PCBs) in order to consolidate the tag into a smaller package for deployment.

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1 Introduction

The purpose of this project was to create a cheap and versatile underwater animal tag. Originally the tag would primarily act as an accelerometer with water pressure and temperature reading capabilities. We later decided to expand the system to incorporate a gyroscope into the design to give more detailed information about the movement of the animal. The tag was designed for use primary on sandbar sharks (Carcharhinus plumbeus) in the Chesapeake Bay, however we attempted to design it in such a way to make it widely applicable to many different types of aquatic animals, in both fresh and saltwater environments. In addition to environmental concerns, the tag has been designed to minimize power usage, memory usage, size, and weight. This is done both to maximize the deployment time of the tag and to minimize its interference with the animal's behavior and habits.

Tags such as this already exist commercially, however they are expensive, costing hundreds to thousands of dollars. Additionally they are single-use because they do not feature a rechargeable battery. This project hopes to overcome both of these limitations by creating a tag that can reused and is available at a lower price point than that of commercially available tags.

2 Initial Prototyping

The initial design and engineering work for this project was done using an Arduino Uno and commercially available breakout boards for the chip set. The boards were individually wired to the Arduino Uno using a solderless breadboard and tested using open source code. Once it was confirmed that all the breakout boards worked individually, we wired them together to the Arduino Uno and combined the code in order for all the sensors to work in unision. At this stage an accelerometer, temperature sensor, pressure sensor, Real Time Clock (RTC), and uSD card reader were in use. All the sensors and the RTC would be read, and then the data from them would be written to a uSD card in the card reader.

Once the wiring was confirmed and the test code operational, the Arduino Uno was changed out for a 3.3V Arduino Pro Mini. The Arduino Pro Mini was chosen for its power efficiency and small form factor. It is, however, less user-friendly than the Arduino Uno as it does not have an onboard USB port or broken-out headers.

Once this change was made, we had to adjust the chips being used to account for the Pro Mini being a 3.3V system, while the Uno was 5v. These adjustments were fairly straightforward.ith the adjustments completed, work began on optimizing the code to reduce the tags power usage .

In addition to making improvements in the code, with the completion of a working breadboard prototype using a 3.3V Arduino Pro Mini we moved the device from a solderless breadboard to a rudimentary point-to-point soldered design. This means that wires were simply laid out where the connections would be made, and soldered into place. This was done in order to make the device more resilient, so that it could be used to take preliminary test data. This first soldered prtype, referred to as prototype 1, did not have the pressure sensor attached. This was because the pressure sensor is the most expensive and delicate sensor and it was not needed for most testing at this stage.

Shortly after the creation of prototype 1 a second prototype, called prototype 2, was created. This prototype was functionally identical to the first one, and also assembled using a point-to-point soldered technique. The difference between prototypes 1 and 2 is that 2 was designed and laid out in a much more streamlined orientation, making it more closely resemble the configuration desired in the final device.

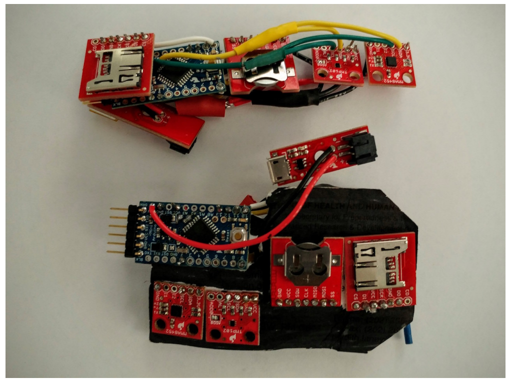

Figure 1: Top: Prototype 2   Bottom: Prototype 1

These two prototypes were used to take initial data. We began creating rudimentary data analysis programs in MATLAB. These functions imported the data from the microSD card, where it was written, and then plotted it for initial checking. The data was then put through a high pass brick wall filter to remove the effects of gravity on the accelerometer data. Finally the data set was rotated such that the X-, Y-, and Z-axis of accelerometry data would correspond to the X, Y, and Z directions of the animals motion.

3 Design

From the previously done MATLAB analysis we determined that a gyroscope would be necessary in order to accurately examine the data in the reference frame of the shark. Additionally, some commerical tags included gyroscopes, and we believed that one could be added to the prototype without large sacrifices to price or performance. As such, a gyroscope on a commercially available breakout board was acquired. After confirming that it worked both independently of the other components and integrated with them, another prototype was constructed to incorporate the gyroscope.

Besides the addition of the gyroscope, this prototype (known as prototype 3) had a radically different design layout from the previous two.. For this prototype perfboard, also know as a solderrd breadboard, was used. This required a much greater degree of design and pre-planning for the connections than did the point-to-point soldering or the solderless breadboard. The layout for the solderless breadboard could not be used for the soldered breadboard for two reasons. The first is that when the solderless breadboard was laid out no thought was given to form factor, as it would never be deployed in any capacity. The second reason is that on the solderless breadboard it is trivial to cross wires. This is not the case on a soldered breadboard. Crossed wires on the solderedbreadboard contribute considerably to both the difficulty of construction and the thickness of the prototype. Since it is desirable to have the protype be thin for possible deployment, and easy to construct, a great amount of care had to be taken in the design of prototype 3.

With the successful completion of prototype 3, data from the gyroscope became available for us to use in the development of analysis code. We did however discover two problems with this prototype. The first issue was that the gyroscope was mounted such that it was oriented at 90° to the accelerometer. This problem was easily solvable by changing the axis labels in analysis, but this is not desirable in the long run. In addition to being mounted in the incorrect orientation the gyroscope was a very large piece of the prototype, and added considerably to the length of the prototype. The desired form factor of the prototype was to be thin and long, and while the gyroscope did fit into this design, it made the prototype longer than was acceptable. Furthermore the reason for the size of the gyroscope appeared to be to enable many features that we did not need for this application.

To reduce the size of the gyroscope board we decided to create a custom printed circuit board (PCB) for the gyroscope chip. To do this we contacted the manufacturer of the commercial board and they provided their designs of the board. With these designs we used the PCB design software Eagle to create a new design for a PCB to break out the gyroscope integrated circuit (IC). This new design was made such that only the features necessary for the prototype would be broken out, and the size and layout of the board would mirror that of the accelerometer. This would allow the accelerometer and custom gyroscope PCB to be stacked on top of each other, adding a slight height increase to the device, but dramatically reducing the length. The width was unaffected.

When the gyroscope designs were completed six PCBs were ordered from the company OSH Park, and enough surface mount components (SMD) were ordered to assemble four fully functional gyroscopes. The assembly process consisted of applying solder paste to the PCB board, placing the SMDs carefully into the paste, and then reflowing the device in a solder reflow oven. Of the four gyroscopes that were assembled, two were fully functional. The two failures were caused by assembly error.

With the successful completion of gyroscope boards work began on prototype 4. Prototype 4 used the same designs as prototype 3. The only difference was the placement of the custom gyroscope board on top of the accelerometer, as opposed to the commercial one at the end of the board. Additionally the custom gyroscope was designed so that when it was mounted in this manner it would have the correct orientation relative to the accelerometer.

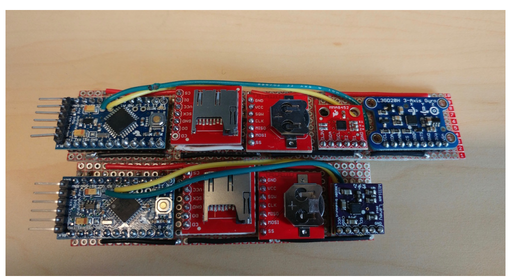

Figure 2: Top: Prototype 3   Bottom: Prototype 4

After we established with our experience on the gyroscope that we could create custom PCB designs, we began work to create a design that would encompass all our devices into a smaller package. We decided to create a stackable design where two PCB boards would be designed to stack on top of each other and 3.3V Arduino Pro Mini. The top of the stack was the arduino, directly below it was a board known as layer 1. Layer 1 consisted of the gyroscope, accelerometer, and microSD card reader. Then a second board went below that, known as layer 2. This board contained the RTC, the RTC battery backup, the LiPo battery connector, and a micro USB slot with a power regulating IC for charging the LiPo. These boards were designed to be the same width as the Arduino but longer than it in order to accommodate the microSD reader and the micro USB connector. These ports constituted the front of the board. The back of the board had header pin holes laid out corresponding to the holes on the Arduino, so that when the boards were laid under the Arduino pins could be put down through all three layers, connecting them together into a single piece. This design had the benefit of being modular, so that we could work on individual layers independently of each other. It also created a very short and narrow package, but would give the device greater height than the prototypes.

We went about creating this device in the same manner as the gyroscope. Designs for layers 1 and 2 were created in Eagle. The PCB designs were then sent to OSH Park for manufacturing, and SMDs were bought to assemble six full Sharkduino systems. Out of five attempts to assemble layer one boards, two boards were fully functional. Out of four attempts to assemble layer two boards, three had functional RTCs and LiPo powering circuits. None had fully functional LiPo charging. The lack of builtin LiPo charging was unfortunate, but did not impede deployment of the boards. The batteries were simply charged off board and then plugged into layer 2.

We are still examining the reason for the failure of the LiPo charging circuitry. One problem is that the female USB connectors were not well attached to the boards using only the solder. As such they would break off or get moved out of place during the reflow. When the microSD connectors were properly secured the charging indicator LED would not activate, even if the correct power was being passed through the USB and the charging chip. We believe that the cause of the LED failure was either from the part not being polarized in the way we expected, or the LED purchased not having the correct electrical characteristics for the circuit we placed it into.

From these PCBs we created two devices that we named Sharkduino V1 A and B. Through testing we found them functionally identical to prototype 4, with the exception of the ability to recharge the LiPo while they were connected to the board.

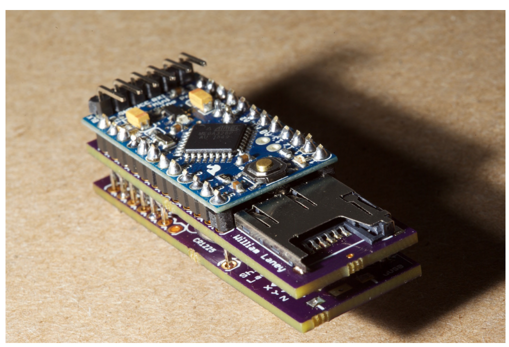

Figure 3: Sharkduino V1

4 Deployment

In order to test the animal tagon live animals we went to the Virginia Institute of Marine Science (VIMS) Eastern Shore Lab (ESL), located in Wachapreague, Virginia. This facility held approximately 20 sandbar sharks of varying sizes in captivity.

Originally we planned to waterproof the early versions of the tag by sealing them into 1 inch-diameter PVC piping. We planned on developing a more effective waterproofing system at a later date. Unfortunately the sharks being held at the ESL were too small to use the PVC enclosure. In order to waterproof the tag we developed a system of using large diameter heat shrink tubing.

The heat shrink solution was accomplished by placing the tag into the heat shrink tubing, heating up flat pieces of metal using a standard clothing iron, and then pressing the hot metal on the end of the heat shrink tubing. This caused the tubing to fuse together and form a waterproof seal. We went through many iterations of this process using different heating elements, applying the heat for different amounts of time, and using two different types of heat shrink. We found the most effective type of heat shrink had thermally activated glue coating the inside.

Throughout the iterations of the heat shrink process we were attaching tags to the sharks. The first deployment we did was with prototype 4 to a sandbar shark for approximately 15 hours overnight. We set the tag to sample at 25 Hz and attached it to a 400mAh LiPo battery that we believed could power the device for a minimum of 40 hours. When we retrieved the tag from the shark the device was still powered on and recording data. The initial data analysis showed that the data appeared to be valid and reliable.

Shortly after retrieving prototype 4 we began to prep it for a second deployment. Unfortunately we found the shark we planned to attach the tag to was not fit for tagging. In order to not waste the tag, which had been prepped and sealed in the heat shrink tubing without the thermally activated glue, we decided to attach it to a cinder block and throw it into the tank in order to do a battery and waterproofing test.

Upon retrieval of the tag we found that the heat shrink seal was faulty and the tag flooded. The tag was destroyed but the micro SD card was still readable; however the data was partially corrupted. We were able to develop a system to recover the partially corrupted data and put it into a readable format. From this data we learned that the tag remained active for three hours before it shut off. While protype four was destroyed, we learned various important lessons. First we learned that the heat shrink without the glue coating is not reliable. Second we learned that microSD cards can be directly exposed to salt water for some time without being totally destroyed. Finally we learned how to recover usable data from partially corrupted microSD cards. We do not however know if the sea water or the sudden shutdown of the Arduino caused the data on the SD card to not be recorded as expected.

With prototype 4 being destroyed, and the Sharkduino V1 devices not yet being constructed, for our next deployment we were forced to use prototype 3. This prototype was larger and heavier than prototype 4, however we determined that it could be deployed on a larger animal without negative consequences to the animal.

We sealed prototype three into a piece of the thermoactive glue heat shrink tubing and attached it to an animal approximately 1m in length. We then left the tag attached for approximately 4 days. When we recovered the tag the power indicator light was off, but this was to be expected with such a long deployment. When the data was on the microSD was examined however we found that there was approximately 90 seconds of data. When the battery was tested by attaching it back to the tag we found that it was not dead, but still had charge in it. This means that the Arduino stopped receiving power approximately 90 seconds after being turned on. We believe that this occurred because of a heat shut off in the battery. When we ironed the heat shrink closed we believe that the temperature at the battery got above the maximum allowable temperature of the battery safety circuity and this caused the battery to stop providing power. When the battery was unplugged and replugged after retrieval this reset the turn off circuitry, and allowed the battery to operate normally.

At this point we had completed assembly of Sharkduino V1 A and B. We sealed them into the thermo activated glue heatshrink and selected animals for them to be attached to. Unfortunately one of the animals we selected was unfit to be tagged. We tagged the shark we could with Sharkduino V1 A and left B sealed up. The following day we opened tag B in order to see if it was still recording data. We found the tag with still powered on but the microSD was not properly locked in. When looking at the data from tag B we found the tag took about 6 hours of data, then stopped. This is presumably when the microSD card came loose.

Figure 4: A Sharkduino V1 attached to a shark. The tag is circled in red.

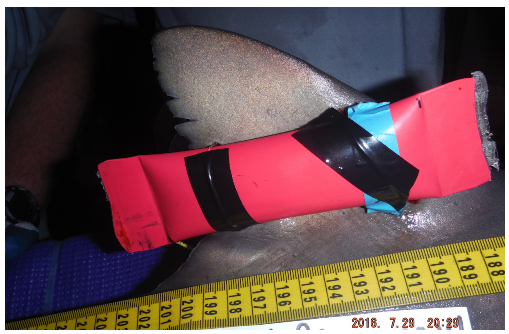

Figure 5: A close up of a Sharkduino V1 attached to a shark.

In order to prevent the tag from coming loose in the future we glued a small plastic piece to the front of Sharkduino V1 B to hold the card in a fixed position. We then prepped the tag for deployment and sealed it. We then removed tag A from the animal and immediately attached tag B in its place. Tag A had been on the animal for slightly over 24 hours at this point.

When we opened tag A we found the power was still on and the SD card contained data. However when we examined the data we discovered that the tag only recorded for about 5 hours. We believe that the microSD card came slightly loose in this tag as well.

We then left the improved version of Tag B on the animal for four days with a 850mAh battery. When we retrieved the tag we found it powered off, and the microSD appeared to be in place. When we examined the data however we found that the tag only took data for about 11 hours. This was significantly less than the expected battery life of a few days. We do not know if the tag shut off because of the battery, the microSD, or because of some other cause. More research is being done to determine the cause of this problem.

5 Further Work

The most pressing piece of future work for the project to create Sharkduino V2 that will correct the problems with the micro SD card reader, along with other more minor problems in the design. In addition to that a new form factor can be developed that will make the tag sit better on the animals fin. The PCB board manufacturer can manufacture non-rectangular boards so it would be possible to design a board that is triangular in order to better mirror the shape of a shark fin. This would allow the boards to have the same amount of surface area, but since there would be not stacking, the device would be thinner and thus interfere less with the movements of the animal.

In addition to improving the design of the tag itself a more robust waterproofing system needs to be developed. The current heat shrink tubing system is effective for short deployments in the tank, but does not have the durability for long deployments in the wild. Furthermore the heat shrink holds a lot of air in with the tag, which would become a problem at greater water depths and pressure. The tank was only about 1.5m deep, so pressure was not a concern. The most conventional solution to this problem is to pot the tag in epoxy. This is the most likely track that we will take as well. The problem with this method is that it is difficult to pot in such a way that mantain easy access to the ports for data retrieval and charging. To overcome this problem we can either have a break in the epoxy for a hatch, or develop a system of wireless charging and data transfer from the device. The wireless method is preferable because it leaves fewer points of failure on the enclosure and is more convenient for the researcher using the tag. Furthermore there are currently no fully wireless accelerometer tags on the market. The wireless approach however is more technologically sophisticated and thus more difficult to design and develop.

Another section for further work on this project is developing a deployment system. Currently the sharks we are working with are kept in captivity so it is trivial to catch the same shark twice, once to apply the tag and once to remove it. In the wild this would not be not the case. It is nearly impossible to catch the same animal more than once. This means that once the tag is attached to an animal in the wild it has to have the capability to detach itself, surface, and transmit its location so that researcher can retrieve it.

Finally the base system developed for this tag is robust and, to a certain degree, modular. It would be fairly straightforward to use the lower power usage and data storage techniques developed during this project with other sensor systems. This means that using the work in this project we could more quickly develop animal tags with different sensor packages in order to fit the needs of the marine scientists.

6 Conclusion

During the course of this project we worked through a process of iterative design to create Sharkduino V1. This process is still ongoing as new features and improvements to the Sharkduino system are being developed. We began with off-the-shelf components and moved to creating custom printed boards of our designs. We have created a tag that is half the price of the nearest competitor, with nearly the same set of features. Finally we have achieved a proof of concept for the tag by deploying it on live animals in a controlled environment. Going forward we hope to further refine the device while keeping the price low. The ultimate goal is to develop a way to conduct marine science research more cheaply, efficiently, and easily so that researchers can focus their time and energy on making new discoveries.