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The State of Data in UNCW Aquaculture

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Chapter 1: Introduction

1.1 Introduction

The UNCW Aquaculture program's goal is to develop and transfer to commercial users cost-effective, environmentally sound technologies for marine food production and to mitigate depletion of marine populations through commercial cultivation or stock enhancement

(<https://uncw.edu/aquaculture/>). UNCW utilizes interns to help aggregate the data needed by professors and graduate students to help reach these goals. The individuals that collect this data learn and employ several different systems to insure the safety and quality of life for the species at the Aquaculture Facility.



Figure 1 UNCW Aquaculture Research Facility

The UNCW Aquaculture Facility (see Figure 1) has expressed the need for a more streamlined process in measuring, recording, and analyzing several parameters in their saltwater fish tanks to help with their goals of stock enhancement. The facility raises several species of fish including the black sea base (see Figure 2) at all different lifecycles. Currently, personnel must use several different instruments, all with different interfaces, to record data and then manually enter this into spreadsheets. This solution has many points for human errors when transcribing accurate measurements. In order for UNCW Aquaculture program to meet its goal more efficiently, it aims to incorporate a data solution that will track various variables, in a more reliable and timely manner so that better models and predictions can be made concerning stock enhancement. This research aims to examine current data collection and analysis at the UNCW Aquaculture Facility and explore alternative solutions to this workflow that would benefit the facility with more efficient, accurate, and financially viable options.



Figure 2 Black Seabass at UNCW Facility

1.2 Background

The worldwide population as of 2016 is 7.3 Billion with a projected 9.7 billion by 2050 (Elferink & Schierhorn, 2016). This means higher demand for food with a finite amount of resources. This has led to research in many fields with the goal of how to better utilize the means we have available (Elferink & Schierhorn, 2016). In the past, when humans have needed more food, we've cleared more land or fished larger areas, but expansion is not the best ecological option anymore (Foley, 2018). Fish and other aquatic life are staples in many diets across the globe and is why aquaculture, or the farming of fish, exists. The National Oceanic and Atmospheric Administration (NOAA) Fisheries division has included aquaculture in its mission by stating, *“Aquaculture is one of a range of technologies needed to meet increasing global demand for seafood, support commercial and recreational fisheries, and restore species and marine habitat.”* (Aquaculture in the Pacific Islands, n.d.)

“Aquaculture—the breeding, rearing, and harvesting of animals and plants in all types of water environments—is one of the most resource-efficient ways to produce protein and has helped improve nutrition and food security in many parts of the world.” (Aquaculture, n.d.). The United States aquaculture seafood industry produced \$1.3 billion worth of seafood in 2014, a small portion of the global \$160.2 billion (Aquaculture, n.d.). Production of fish in aquaculture facilities will need to grow as NOAA limits fishing of wild fisheries to bring fish stocks to sustainable levels (Fisheries, 2018). Aquaculture can provide more of the world's population with a healthy protein source and reduce ecological strain on the environment. Calculations published in Aug of 2017 estimate that 0.015% of ocean surface can, while properly farmed, produce the same amount of seafood as the world's natural fisheries combined (Gentry, et al., 2017).

Aquaculture production has grown over the past decade. However, due to rapid expansion, the industry is now faced with social, economic, and biological issues that weren't detrimental, and in some cases even present, a few decades ago (Føre, et al., 2017). The problem of FIFO, or Fish in: Fish out, has been a big problem in aquaculture (Fish in: Fish Out (FIFO) ratios, n.d.). FIFO, at the root, is a problem concerning feeding farm raised fish. Typically, farm raised fish consume fish meal, that is made from wild caught fish. Computed FIFO ratios in 2000 were 0.63, meaning it took 0.63 kg of wild fish to produce 1 kg of farmed fish, but by 2015 that FIFO ratio went down to 0.22 (Fish in: Fish Out (FIFO) ratios, n.d.). This means that aqua-culturists have increased the overall efficiency in which they grow fish, but each species of fish has its own conversion ratio. The salmon and trout FIFO ratio was 2.57 in 2000 and went below one in 2015 when it reached 0.82, which means that it took 15 years before farming salmon was ecologically sound (Fish in: Fish Out (FIFO) ratios, n.d.). Issues concerning the control of living conditions directly affects the ability of many species to reach marketable size while farming. The aquaculture living conditions also directly impact both the species, through pathogens, pollutants, and parasites, but also the environment (Føre, et al., 2017).

The nature of aquaculture is to grow and harvest animals that live in far different medium than their farmers. Aqua-culturists rely on scientists and data to find solutions that surround the challenges of indirect observation that will help them ultimately produce marketable size fish.

“...a regime based on direct observation alone may be insufficient to acquire the levels of knowledge, monitoring and control required to tackle the challenges of modern fish farming. Instead, what is required for modern large-scale fish farming are technological tools that enable remote monitoring of large populations of fish in a manner that yields

data that can be used to adjust and modify day-to-day operations to optimize the growth and survival of the fish.” (Føre, et al., 2017)

Aqua-cultural scientists worldwide have been working on various solutions to develop high-value and high-demand species that can be grown in high densities. Precision Fish Farming, PFF, has been at the source of many answers involving the myriad of aquaculture problems (Føre, et al., 2017). PFF is based on Precision Livestock farming, which includes animal variables, parameters involving animal behavior, models to help run various variable outcomes, and predictions analytics (Føre, et al., 2017). Precision Fish Farming has the potential to solve rapidly growing global food supply problems with our rapidly growing technology. It is focused on leveraging technology to optimize growth and survival of aquatic species grown in aquaculture facilities.

Chapter 2: Review and Analysis

Globally, aquaculture is concerned with maximizing growth rate and minimizing production costs (Allen & Steeby, 2011). UNCW's aquaculture program works to produce cost-effective, environmentally sound technologies to boost populations and stock health in aquaculture environments. Dr. Watanabe, Research Professor and Director of Finfish Aquaculture at the Center of Marine Science, and researchers in this field are interested in effective, efficient, and economical solutions to collect, store, and analyze data in regard to water parameters of their aquaculture tanks (Polera, 2018).

2.1 UNCW's Current Solution

UNCW currently utilizes several different hardware, software, and human resources to monitor the water quality in their tanks in order to advance the aquatic species health and populations in their facility. Paul Dimling, Research Assistant at the UNCW Finfish Aquaculture Research Facility, worked with students from the UNCW MSCSIS program to better understand the shortcomings that may be solved with improved technologies around aquaculture data collection and storage.

2.1.1 Data Collection

Data collection varies at the Finfish Aquaculture Research Facility depending on the type of data and the current study. Various collection methods exist to collect the same data point; however, overall cost to the facility limits the potential solutions. Furthermore, collection methods are subject to the type data being collected. There are two main types of data: Critical Data, and Research Data. Critical data is any data that pertains to the immediate risk of health to the specimens at the research facility. This data includes parameters such as temperature or water levels in the aquaculture tanks. If these critical parameters start to move out of bounds,

immediate action is necessary. Research data is any data parameters that furthers the current study, which is varied depending on the goals of the study. These two data types are not mutually exclusive; parameters such as oxygen reduction potential are important for the sustainment of species and potential studies.

With respect to critical data, the UNCW Aquaculture Facility monitors limited parameters in real-time. Temperature and sump levels are critical for the aquatic life at the facility. These are measured and monitored with a Sensaphone 800. The Sensephone is largely automated and allows different parameters to be measured, and if this falls outside of a user defined range, it calls up to eight people. The general dataflow for the Sensaphone is shown in Figure 3.

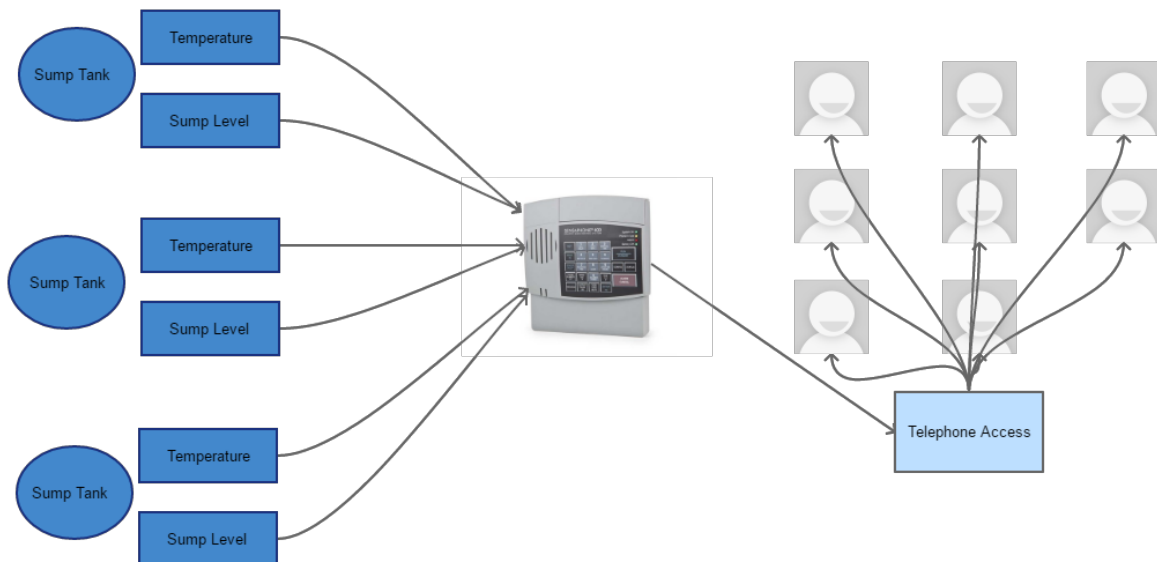


Figure 3 Sensaphone flow diagram

The Sensaphone will programmatically call people on an ordered list. If someone responds, it will stop calling. It is then the responsibility of the responding person to come to the facility and

make sure things are in order. According to Research Assistant Mr. Dimling, there is a high rate of false positives that are logged by the Sensaphone. The Sensaphone does not log any data points; it is strictly for alerting researchers if the readings are out range.

With respect to research data, researchers collect research data using several different manufacturers of probes to analyze and display different water parameters. Research assistants gather probes, paper-strip tests, paper, and pencils and walk the compound. The granular focus and goals of the studies change over time, and the exact data collected reflects these changes. The researchers record outputs from the various probes and paper-strip tests onto paper, while other readings are just checked for certain bounds and never recorded. The recording of paper-strip tests with pencil and paper is simple, but when asked about the electronic probes several concerns arose. Only some of these probes have on board memory and integrated data managers. The few that do are left unused because of the older computers found at the facility have difficulty in running the applications necessary to extract and manage the data.

The manufacturers of the probes used at the aquaculture research facility at UNCW are primarily YSI and Hach. These sensors and multiparameter meters can range anywhere from a couple hundred to tens of thousands of dollars. When shadowing the technicians, they noted some of these probes did not work properly. It is unknown what left them only partially operational, but funds to replace them are absent. The technicians follow a route to a series of aquaculture tanks that hold an assortment of different species of fish. The technicians visually inspect the fish, feed them, and take several measurements.

UNCW moved from large adult Black Sea Bass and Flounder tanks, to younger fish. The technicians explained that they count and separate the younger life cycles often. This is done to inspect the overall specimen health and mitigate any overcrowding as the fish grow. The water

parameters measured in these extremely varied aquaculture tanks were just as varied. Here, as in the adult tanks, the researchers used various paper-strip tests along with electronic probes. The technicians explained that it truly depends on the type of current research to what was most important for tracking and monitoring.

A visual representation of data collection workflow can be found in Figure 4. Dotted lines in the figure represent tasks that are done depending on the current research.

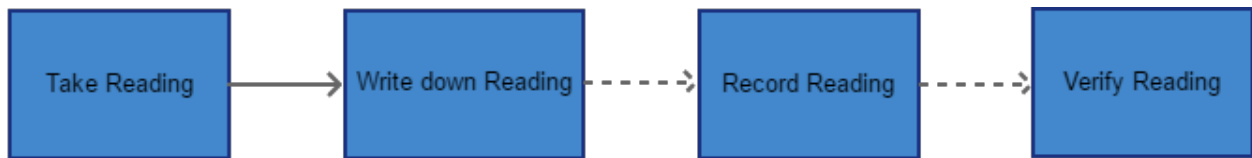


Figure 4 UNCW Facility Workflow Diagram

The research data parameters are wide and varied, however there are some that are almost universal. The basic gamut for aquaculture species health includes pH, oxygen reduction potential, dissolved oxygen, conductivity, temperature, and salinity. The technicians utilize their probes for these measurements.

2.1.2 Data Analysis

The UNCW Finfish Aquaculture Research Facility collects data to accomplish their goal to yield profitable, ecologically sound practices to enhance populations and stock health in aquaculture environments. The analysis of this data is where the progress is made. The current system is as varied as the data collection process.

The research assistants visit each tank and use various probes to take readings, they then aggregate data on printed forms. If the research calls for historic tracking of water parameters, the data is entered into Excel spreadsheets, so researchers can chart and graph different parameters over time. Researchers often go over the entered data to verify measurements are within acceptable bounds. The data is then utilized for the current study. The use of this

information in future studies is difficult to predict. Researchers have realized the importance of historical data charted over many years (Polera, 2018). The data analysis and management system currently used limits the readiness to future researchers.

2.2 Factors of Evaluation

In this section, we review the methods that the UNCW Aquaculture Research Facility currently uses to collect and formulate data. Currently, data is being collected twice in the form of critical data and research data. The data does not always make its way to an electric form of storage where it can be easily queried by both current researchers and future ones that might need historical data. The requirements outlined below will give an overview of the project constraints and a basis in which to evaluate other potential solutions.

1. Data Collection

- a. **Parameters** – Researchers need to be able to collect the information they need to accomplish their research.
- b. **Accurate** – The hardware must be able to accurately measure the given parameters at or better than the current hardware used.
- c. **Affordable** – The hardware and software must fall within the budget of the research facility.

2. Data Analysis

- a. **Access** – Researchers at the facility must be able to access their data from the onsite lab and at their offices. The data should be available in different formats for distribution to other researchers.

- b. History** – Researchers utilize data points actively collected now, however many researchers in the future should be able to employ this information without the need to collect old paper data journals or search through excel spreadsheets.
- c. Alert** – As mentioned in access, researches need to know the moment tank water levels or temperatures are out of bounds for the safety of the aquatic life and the integrity of their research. Limiting the number of false positives in the alerts should be a priority.
- d. Interface** – An insightful and easy to read interface should relay important information about specimen health, while still allowing user defined aggregation of data.

2.2 Readymade Solutions

There are a few different solutions that are available on the commercial market today for collecting and analyzing water parameters. Two possible solutions closet to meeting the needs of the research facility are the Hach Mobile Sensor Management solution and the YSI Continuous Monitoring and Control solution.

2.2.1 Hach Mobile Sensor Management

The Hach Mobile Sensor Management is a part of the Claros Instrument Management suite of products. The system allows for users to view quality measurements from anywhere, at any time on web devices. The system has built in alerts and maintenance instructions. The management system allows for a broad range of measurements.

2.2.1.1 Hach Data Collection Parameters

The management system is built on a à la carte principal. Users have a central management hub that they then obtain specific sensors for their use case. The system can measure a variety of water parameters to include:

- Nitrate
- Orthophosphate
- Dissolved Oxygen
- pH
- Oxygen Reduction Potential
- Turbidity
- Organic Load
- Sludge height
- Conductivity
- Ammonium

The accuracy of the system depends on the sensors in the system. The conductivity sensor has an accuracy of $\pm 2\%$ of readings above $200 \mu\text{S}/\text{cm}$. The dissolved oxygen has an accuracy of $\pm 0.05 \text{ ppm}$ below 1 ppm $\pm 0.1 \text{ ppm}$ below 5 ppm $\pm 0.2 \text{ ppm}$ above 5 ppm . The pH sensor does not have a given accuracy but has an effective sensitivity of $\pm 0.01 \text{ pH}$.

Prices for the various components that make up the Hach Mobile Sensor Management system are not easily accessed. A quote was requested and has yet to be answered by the company.

2.2.1.2 Hach Data Analysis Access

The Mobile Sensor Management tool has access to live water parameter readings through a web interface as can be seen in Figure 5. The solution is geared towards live access to data for sensor calibration and keeping track of real time water parameter readings.

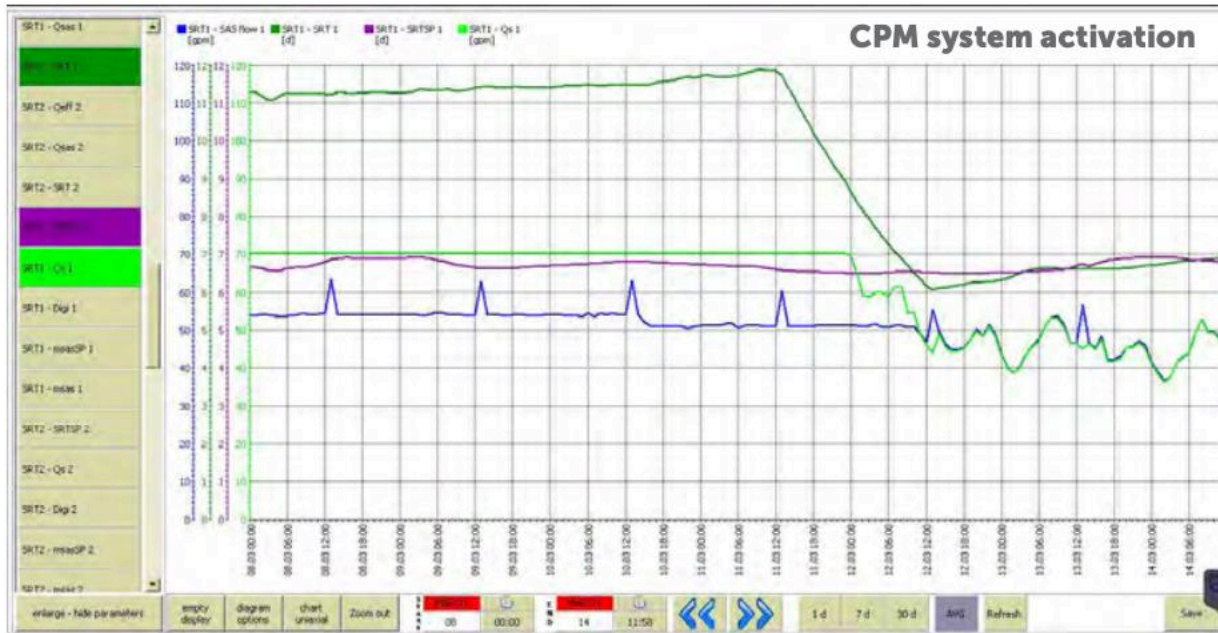


Figure 5 Hach MSM User Interface

Hach's system does support long time data storage and management but is heavily burdened by unknown data storage and access fees. The data store is proprietary and not easily accessed or freely distributed for collaboration with other researchers.

The management system allows for setting thresholds and sending alerts to authorized researchers. These alerts can be sent as emails or SMS messages.

The Hach interface is a web application. This allows for use on mobile and desktop devices.

The ability to look at current and historic information is a great attribute of Hach's solution, however the lack of easily downloading information is a major drawback.

2.2.2 YSI Continuous Monitoring and Control

2.2.2.1 YSI Data Collection Parameters

The monitoring and control system is built on a à la carte principal. Users have a phone application that they can use to log into the central hub. The system can measure a variety of water parameters to include:

- Dissolved Oxygen
- pH
- Oxygen Reduction Potential
- Conductivity
- Temperature

The accuracy of the system depends on the sensors in the system. Temperature has an accuracy of $\pm 0.2^{\circ}\text{C}$. pH has an accuracy of ± 0.2 pH. ORP has an accuracy of ± 20 mV. Conductivity has an accuracy of $\pm 0.5\%$ of range (0-100 mS); $\pm 1.0\%$ of reading (100-200 mS). Dissolved oxygen has an accuracy of $\pm 2\%$ or ± 0.2 mg/L whichever is greater (0-200%) (0-20 mg/L), $\pm 6\%$ of reading (200- 500%) (20-60 mg/L). These are with the recommended YSI 5200A system.

When inquiring about the YSI 5200A system and the control, cables and sensors for DO, pH, ORP, conductivity, and temperature the list price came to \$4,694.00. The phone application is \$10, plus a monthly access fee depending on the number of sensors and the history storage.

2.2.2.2 YSI Data Analysis Access

The use of a native phone application is an asset to check real time measurements and to receive important notifications about the health and wellness of species.

Access to data history through the monitoring and control solution is controlled by the subscription service that the user wants to pay. The user interface for YSI's solution can be seen in Figure 6. The data storage is proprietary and does not look as if it can be backed up locally and distributed to other researchers.



Figure 6 YSI User Interface

YSI's solution can send email and SMS messages to authorized researchers when the values of water parameters fall out of bounds.

The YSI solution's main failure point comes to the way that researchers interface data. The phone application data interface does not translate well for researchers scouring scores of data for examination. The YSI solution relies on a mobile interface that looks nice but is effectively limited to real-time. It is particularly limited on data aggregating.

2.3 Custom Solution

Designing and implementing a custom solution for the Aquaculture Research Facility has several advantages, a few being the ability to target the needs of the facility and the ability for financial efficiency by utilizing technologies that have the same level of performance for a reduced cost.

2.3.1 Custom Data Collection

The custom solution's data collection method pairs Atlas Scientific probes for data collection and a Raspberry PI microcomputer to store, process, and send that data to the cloud. The hardware utilized for the collection will be a Raspberry Pi 3 Model B, Atlas Scientific pH probe, Atlas Scientific dissolved oxygen probe, Atlas Scientific conductivity probe, Atlas Scientific oxygen reduction potential probe, Atlas Scientific water temperature probe, and Adafruit air temperature, humidity, pressure and gas sensor.

The Atlas Scientific probes offer the following water parameters:

- Dissolved Oxygen
- pH
- Oxygen Reduction Potential
- Conductivity

- Temperature
- CO2

The raspberry pi 3 (Figure 7) is the third-generation of a series of microcomputer that was

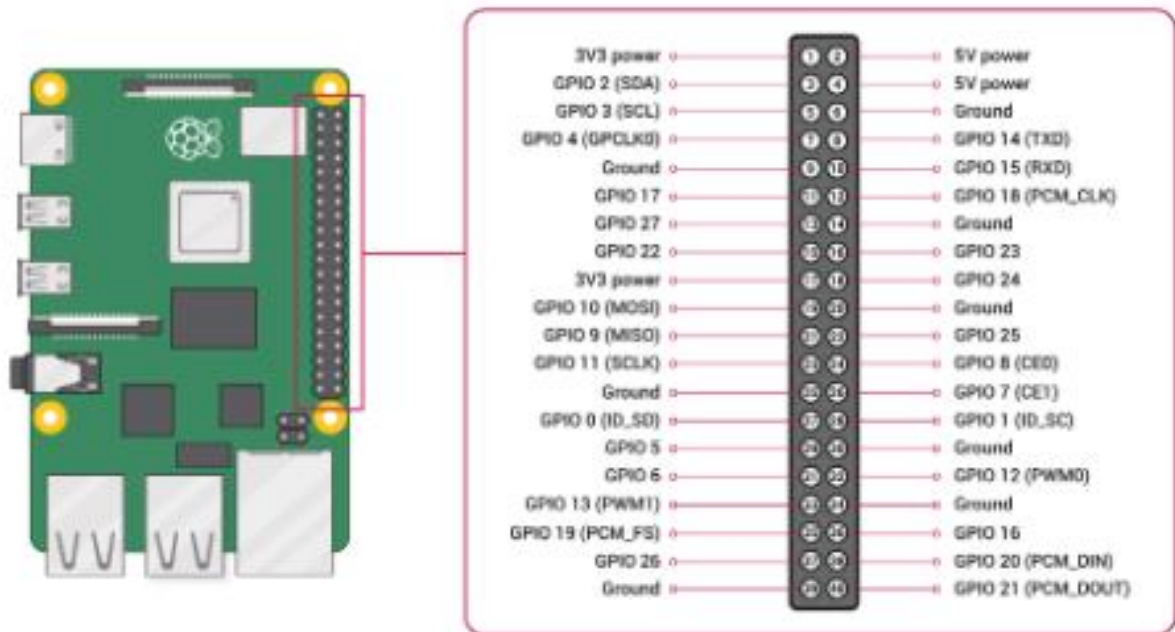


Figure 7 Raspberry Pi Layout

released in February 2016. It contains a Quad Core 1.2 GHz 64bit CPU with 1GB of RAM. It includes a BCM43438 wireless LAN and Bluetooth Low Energy board built in for wireless communications and a wired Ethernet port. It has 40 general-purpose input/output (GPIO) pins for interfacing various with controllers, sensors, and nearly an unlimited source of other hardware. The raspberry pi 3 utilizes a micro SD card slot for loading the operating system. The operation system loaded Raspbian Jessie, which is a Linux based operating system.

The data sheet for the Atlas-Scientific pH sensor (Figure 8) specifies that it has a range of 0-14 and has a resolution of +/-0.001 and an accuracy of +/- 0.002 and a response time of 95% in one second. It has an operation temperature range of -5 – 99 degrees Celsius. It has a life

expectancy of around 2.5 years and has a recalibration period of every year. It can be fully submerged in fresh or salt water indefinitely. It measures the hydrogen ion activity in a liquid.



Figure 8 Atlas-Scientific pH Sensor

Atlas-Scientific datasheet specifies the ORP Sensor (Figure 9) to have a range of ± 2000 millivolts and an accuracy of ± 1 millivolt. It has a response time of 95% in one second and has a maximum pressure of 100 pounds per square inch. It has a maximum operation depth of 60 meters and a 1-80 degree Celsius temperature range. It has a life expectancy of 2 years and recalibration period of every year. It can be fully submerged in fresh or salt water indefinitely. It measures electron activity in a liquid.



Figure 9 Atlas-Scientific ORP Sensor

The Atlas-Scientific datasheet specifies the DO sensor (Figure 10) has a range of 0-100 milligrams per liter and an accuracy of ± 0.05 milligrams per liter. It has a response time of about 0.3 milligrams per liter per second and has a max pressure of 500 pounds per square inch. It has a max depth rating of 343 meters and an operating temperature range of 1-50 degrees Celsius. It has a life expectancy of 5 years and a recalibration period of every year. It can be submerged in fresh or saltwater for up to 18 months before maintenance is needed. Oxygen

molecules diffuse through the probes membranes and this is converted into voltage that is the output. When the voltage is 0 it means that there is no oxygen in the water.



Figure 10 Atlas-Scientific DO Sensor

The Atlas-Scientific datasheet specifies the EC sensor (Figure 11) has a range of 5-200,000 micro S per centimeter and an accuracy of +/- 2% with a response time of 90% in one second. It has a max pressure of 500 pounds per square inch and a max depth of 343 meters. It can operate in a temperature range of 1-110 degrees Celsius. It has a life expectancy of 10 years and a recalibration period of 10 years. It can be submerged in fresh or salt water indefinitely. Using two electrodes with AC voltage applied it measures free electrolytes in the water which can give insights on nutrients, salts, or impurities in water.

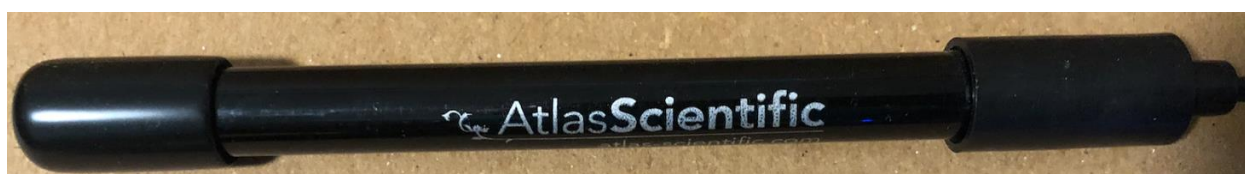


Figure 11 Atlas-Scientific EC Sensor

The Atlas-Scientific datasheet specifies the temperature sensor (Figure 12) has a range of -200-850 degrees Celsius and an accuracy of +/- $(0.15 + (0.002 * t))$ with a reaction time of 90% in 13 seconds. It has a life expectancy of 15 years and a recalibration period of 3-5 years. It contains a platinum resistor which changes the resistance of the electric current flowing through it.



Figure 12 Atlas-Scientific Temperature Sensor

The Atlas-Scientific EZO Boards (Figures 13 -17) are small circuit boards that have Universal Asynchronous Receiver/Transmitter (UART) and Inter-Integrated Circuit (I2C) data protocols built in. They take the output from the sensors and manage the signals back to the microcomputer, in our case the Raspberry Pi 3 in either protocol, however the Raspberry Pi 3 has limitations in UART mode, so I2C was the chosen protocol.



Figure 14 Atlas-Scientific pH EZO



Figure 13 Atlas-Scientific Temperature EZO



Figure 15 Atlas-Scientific DO EZO



Figure 16 Atlas-Scientific EC EZO



Figure 17 Atlas-Scientific ORP EZO

The Atlas-Scientific Voltage Isolator, as seen in Figure 18, electrically isolates the various sensors so that they do not interfere with each other. Without the Isolator boards the reading from more than one sensor can impact the reading of the other sensors. It has an input voltage of 3–5 Volts DC and a consumption of 15-20 milliamps. They are used on the pH, ORD, DO, and EC sensors. The temperature sensor does not require electrical isolation.



Figure 18 Atlas-Scientific Voltage Isolator

The overall system was first assembled on solderless breadboards, see Figure 19. This allows easy testing and reconfigurability of the system in case of wiring errors or broken components. After the initial testing of the components I soldered the connectors and wires to prototype boards for a more reliable and rugged connection, see Figure 20.



Figure 19 Custom Solution Hardware - Breadboard

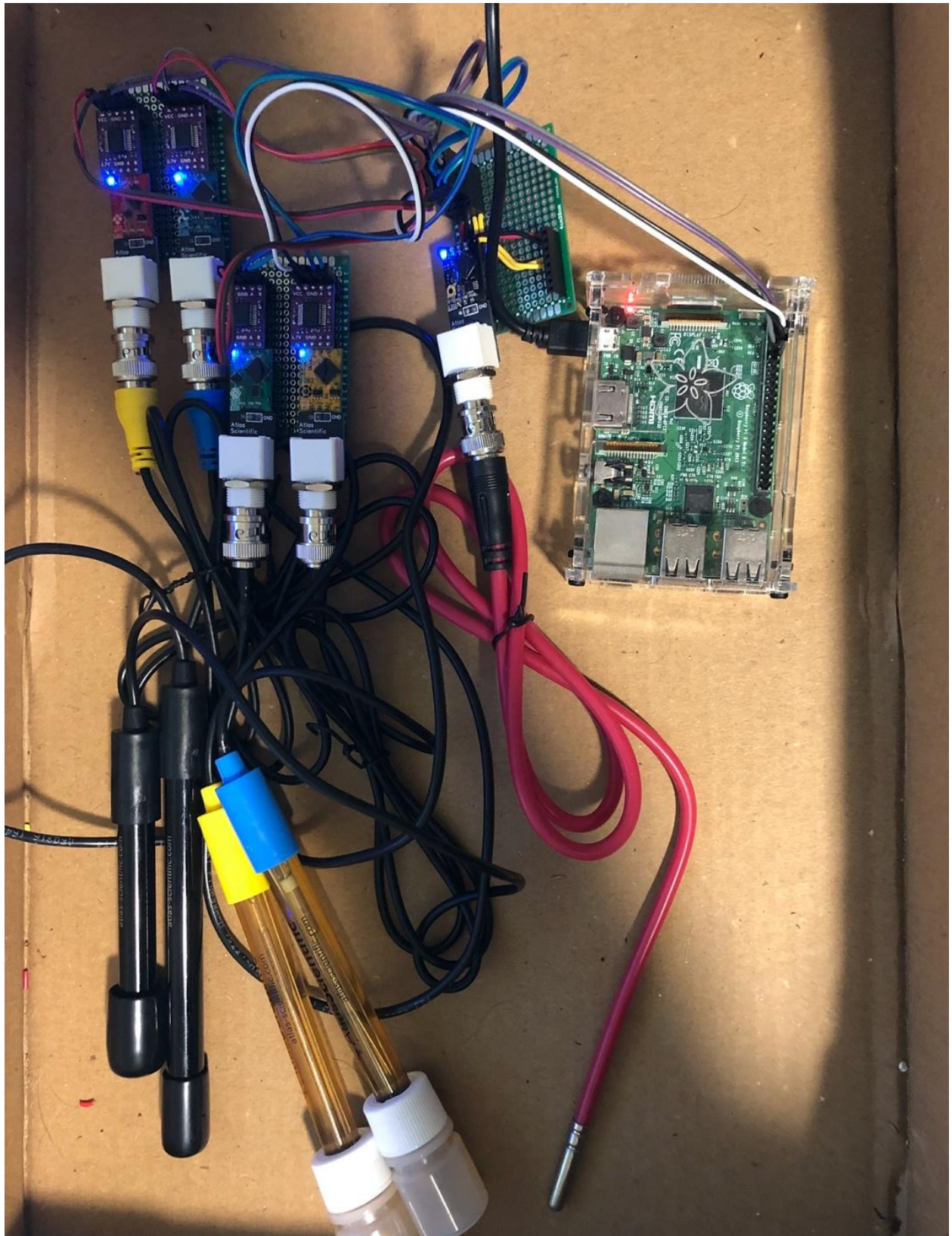


Figure 20 Custom Solution Hardware - Soldered

At this point, the sensors were outputting electrical signals that were interpreted by their EZO boards and were being sent to the Raspberry Pi 3 via the I2C protocol. The GPIO pins 2 (SDA) and 3 (SCL) were connected to the outputs of all the EZO boards. The SDA pin is in charge of data and the SCL is the clock. The clock synchronizes while the data sends over the other line. These probes can be purchased for \$879.00 for a kit of all the sensors, a Raspberry PI is \$50, and cloud access fees for data storage. This overall price is on average what one probe costs for YSI or Hach.

3.2.2 Custom Data Analysis

The custom data analysis solution was designed to give real time access to water parameters through a web portal. The custom solution is able to give lifetime access to all records to researchers. The data can be downloaded for use in other applications. Utilizing cloud functions, the custom solution is able to send SMS and/or email notifications to researchers about data out of preset bounds. The interface is comprised of a modern responsive web application that can be used at a desktop, phone, or tablet.

3.3 Solution Selection

This project's purpose is to build, buy, and utilize the preexisting solution, or a combination thereof to meet the data collection and data analysis needs of the UNCW Aquaculture Research Facility. The project's aim is to leverage software and hardware to provide reliable data collection and analysis all while placing minimal impact on both finances and resources at the facility.

The current methods of collection, alerts, and analysis are cost effective and allow researchers to complete their work, however the long term digital storage will most assuredly provide future opportunities that would not simply not be available with a paper and electronic shared system.

The Hach Mobile Sensor Management solution has a good system for calibrating sensors and keeping track of real time data but lacks the long-term history and reporting interface that is needed by the Aquaculture research facility. While the YSI offers a solution that meets the needs of the research facility, but at nearly \$5000 would not be cost prohibitive. The custom solution offers the requirements as the YSI solution, but at a fifth of the price. The custom solution also offers researchers a reliable way to collect, store, share, and analyze data now and in the future. We now examine the details and design of the custom solution.

Chapter 3: Methodology and Plan

3.1 Custom Solution Data Flow

The custom solution utilizes a the Raspberry Pi microcontroller and the appropriate sensors (Atlas Scientific) to collect data and then passes this through several Azure services (See Figure 21). This data will be collected every minute and stored locally on the Raspberry Pi. Every minute this data will also be uploaded via Wi-Fi to Azure IoT hub. Azure IoT hub manages edge device security with per-device authentication and has built-in device management. Azure IoT hub also scales well with the ability to create and provision devices with a command line interface.












 ASP-HappyFish-ae25	App Service plan
 fish (fish-prod-sql/fish)	SQL database
 fish-prod-sql	SQL server
 fish_prod (fish-prod-sql/fish_prod)	SQL database
 HappyFish	App Service
 happyfish-cosmos-db	Azure Cosmos DB account
 happyfish-fuction-app	App Service
 happyfish-fuction-app	Application Insights
 HappyFish-IoT-Hub	IoT Hub
 happyfishmessagstorage	Storage account
 HappyFishWebPlan	App Service plan

Figure 21 Azure Services

The Azure Dashboard gives up to date hub usage with how many messages have been sent along with the total devices connected. Azure Serverless Functions (See Figure 22) is responsible for device authorization and any possible data sanitization and save the data into Azure Cosmos DB (See Figure 23). The overall flow from Azure IoT hub to Azure Functions to Azure Cosmos DB can be seen in (See Figure 24).

DATE (UTC) ▾	SUCCESS ▾	RESULT CODE ▾	DURATION (MS) ▾	OPERATION ID ▾
2020-04-23 02:48:31.656	✔	0	25.5319	bb660913f720d044ada4d185239ccb82
2020-04-23 02:47:31.435	✔	0	23.7071	eea79de9dcbcb744963b8d8a2038fe6b
2020-04-23 02:46:31.205	✔	0	32.8134	5a24f5f56c07094c81dd3e9064a1691f
2020-04-23 02:45:30.953	✔	0	9.409500000000001	82f0a8f4b1cc2c4dbf965ee0f4aa6ccd
2020-04-23 02:44:30.721	✔	0	44.1813	1c98c61c91e8a84bbd5247bc9fdb6077
2020-04-23 02:43:53.790	✔	0	1547.0567	a64a16c1aa5f64429c4fe3a3a2a5d04a
2020-04-23 02:42:30.243	✔	0	13.985800000000001	a7248946c90aa943b78f930208256d8d
2020-04-23 02:41:29.999	✔	0	10.395000000000001	2a40823e56954b498d9c5b781012f83f
2020-04-23 02:40:29.796	✔	0	13.172500000000001	7398aa814d7f48aef1d8ea62dfc5e5
2020-04-23 02:39:29.539	✔	0	11.718	592fd3a6cbdaf240904e6229cac7aaec
2020-04-23 02:38:29.289	✔	0	25.282500000000002	d402b30af05b6a409dae9c8b098ce2ec
2020-04-23 02:37:29.046	✔	0	11.5303	d65ecbf49f2f2c439f4c5367de984fe1

Figure 22 Azure Function Messages

id	/device_id
f8bb6016-30c8-4e76-b8a5-b542e9897d6f	uncw-device-1
2a3ad608-403e-487d-af29-660fd8a7c921	uncw-device-1
c10cdf75-5e5d-47b1-b090-ce600c617ece	uncw-device-1
25fb7d77-1bbf-4d9a-8ac9-ecb06b9df282	uncw-device-1
d7b62083-3f9d-4f4b-b897-b17808ca1709	uncw-device-1
60d01e48-69b7-43d1-a481-e63eeabbd271	uncw-device-1
ede3bc87-5a06-49d9-89cc-a312c0258fda	uncw-device-1
8bf3b844-d2f1-48f8-82a5-72b36292bc1a	uncw-device-1
82fe08b7-ce7e-4947-9298-73807f03a455	uncw-device-1
3fa1113b-213e-434e-9637-f3776cbbffbd	uncw-device-1
bd38f63a-328c-4ca6-afc8-f922a28dced8	uncw-device-1

Figure 23 Azure Cosmos DB Messages



Figure 24 Dataflow from IoT Hub to Function to Cosmos DB

Cosmos DB is a NoSQL database that will hold all of the data per device. This can be scaled out for minimal cost and will give users a long history of device collection that can then be placed to specific locations with the use of a management database that will utilize a conventional SQL database. The management database will hold all user, groups, locations and device mappings. This allows the integrity of a relational database with the lessoned cost of a non-relational database. These databases will feed a web API for mobile applications and an MVC web application. This Web API and MVC project will be hosted on Azure and will sit behind a load balancer to handle requests. The entire flow described from ingestion to delivery can be seen in Figure 25.

Data Flow

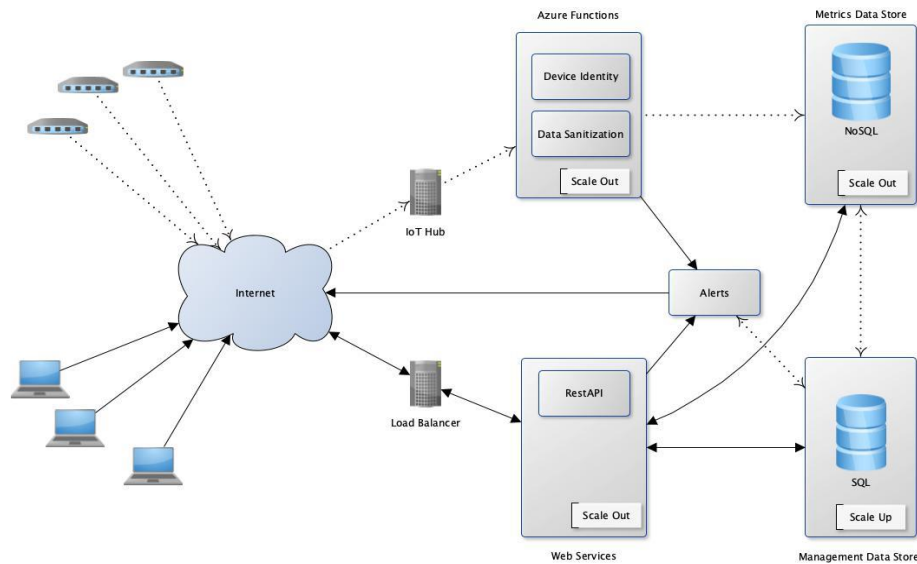


Figure 25 Data Flow of Custom Solution

3.2 Custom Solution Web Architecture

The solution will consist of Azure IoT hub to receive the messages and Azure Functions to sanitize and send that data to a NoSQL Azure Cosmos DB (See Figure 26). It will use a SQL database for account and device information. A MVC web application will be hosted in Azure App Services and a Web API will deliver data to a native iOS and Android applications.

The web architecture allows the platform to be extensible to desktop applications or a future single page web application with access to data through the REST API.

Web Architecture

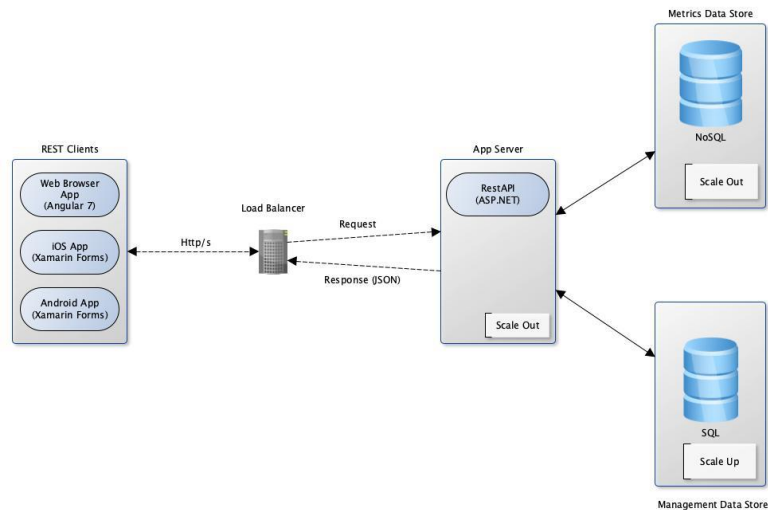


Figure 26 Web Architecture for Custom Solution

Chapter 4: System Implementation and Evaluation

4.1 System Implementation

The custom solution was built using several different technologies and services. The web application was built with ASP.NET MVC5. This framework utilizes a Model View Controller architecture with C# POCO classes for the model, HTML Razor pages for the view, and C# Controllers. The web application uses Entity framework for the scaffolding models from the database. The iOS and Android applications were build using Xamarin Forms. Which allows about 80% of reuse of code between both platforms. It also allows tapping directly into native Objective C iOS and Java Android Libraries to create custom controls. The applications are built in XAML and C# and a Model, View, View/Model architecture approach as taken to decouple views from models. The mobile application uses a local Realm database for caching of measurements and user data. The measurement data is stored in a Cosmos database which is a nonrelational database and user data is stored in a SQL Azure database. Azure functions were used to transport requests from the probe microcontroller into the Cosmos database. They were also used to set alerts on measurements as they passed through the system.

The web application (See Figure 27) gives real time insights into the various water parameters of selected tanks. User can see some background (See Figure 28) and log in (See Figure 29). The web application also allows users to update their name, email, and password (See Figure 30). Once logged in, users can see graphs of parameter measurements of selected tanks (See Figure 31). Individual tanks can be selected along with a time frame to analyze data. This same premise is used with data tables (See Figure 32).



Figure 27 Web Home Page

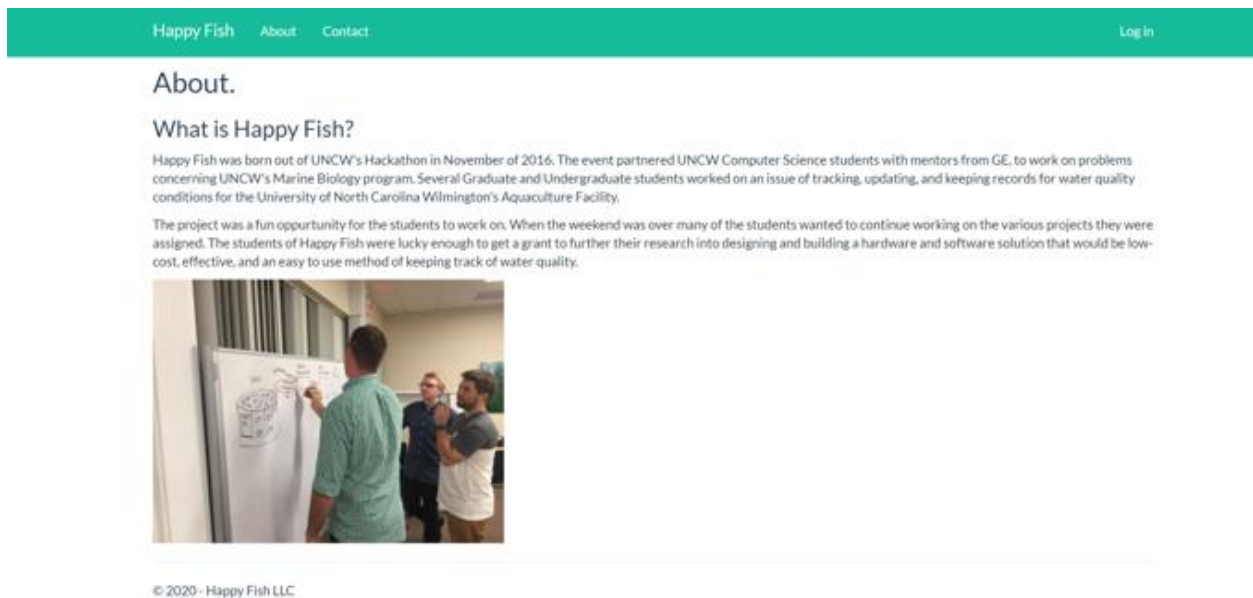


Figure 28 Web About Page

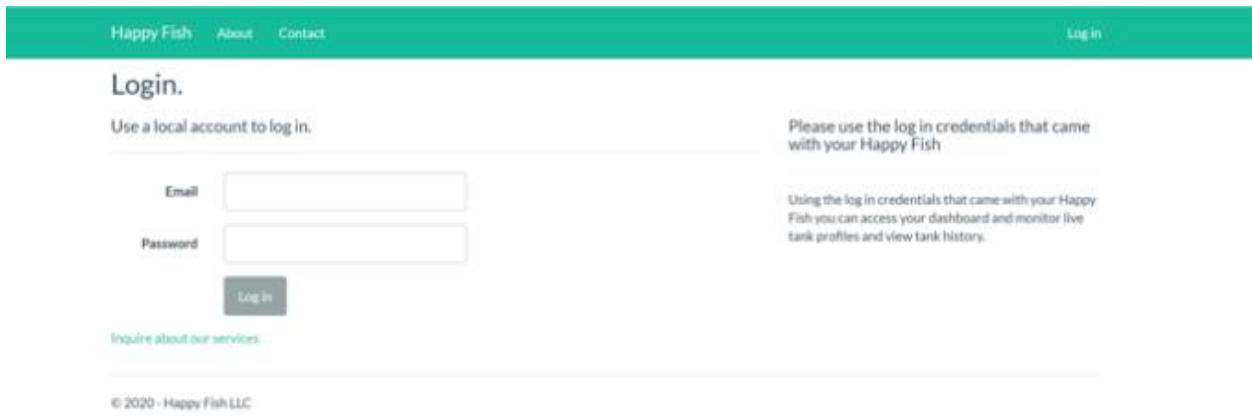


Figure 29 Web Login Page

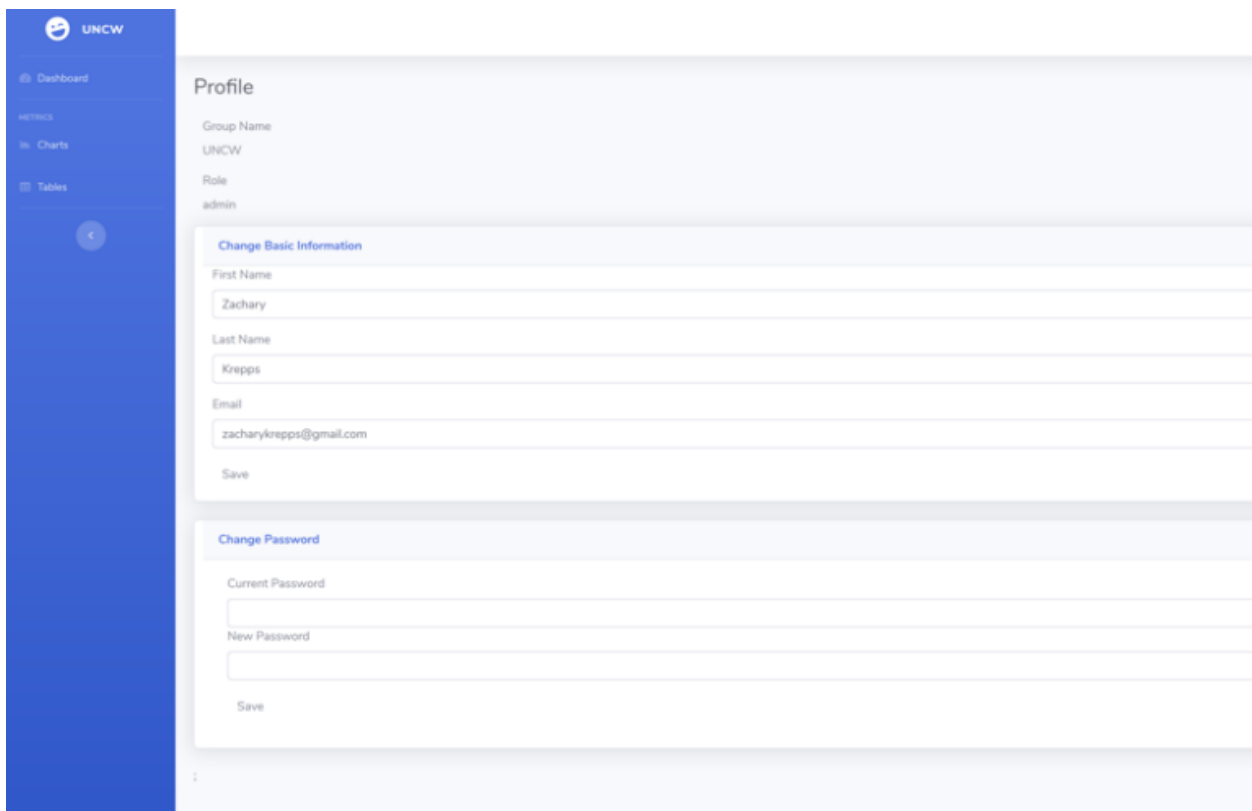


Figure 30 Web Profile Page



Figure 31 Web Graph Page

The figure shows a dashboard with a blue sidebar containing 'Dashboard', 'Metrics', 'Charts', and 'Tables'. The main content area is titled 'Tables' and includes two dropdown menus: 'Selected Device' (set to 'Test Device') and 'Timeframe' (set to 'Last 24 Hours').

Below the dropdowns, there is a 'Show 10 entries' control. The table displays the following data:

Date	Time	Conductivity	pH
11/7/2020	3:05 AM	0.00,0.00,1.000	2.635
11/7/2020	3:10 AM	0.00,0.00,1.000	5.688
11/7/2020	3:15 AM	0.00,0.00,1.000	6.241
11/7/2020	3:20 AM	0.00,0.00,1.000	6.170
11/7/2020	3:25 AM	0.00,0.00,1.000	1.264
11/7/2020	3:30 AM	0.00,0.00,1.000	4.110
11/7/2020	3:35 AM	0.00,0.00,1.000	6.20
11/7/2020	3:40 AM	0.00,0.00,1.000	2.357
11/7/2020	3:45 AM	0.00,0.00,1.000	3.634
11/7/2020	3:50 AM	0.00,0.00,1.000	5.550

At the bottom of the table, it says 'Showing 1 to 10 of 348 entries'.

Figure 32 Web Table Page

The mobile application (See Figure 33) runs and looks the same on both iOS and Android. After users log in (See Figure 34) they are taken to their dashboard (See Figure 35). The dashboard shows users the last 24 hour metrics on all of their devices. It also gives any alerts to users for parameters out of bounds. The side menu (See figure 36) permits users to navigate through the app. The native mobile app gives users the same ability as the web application to view tables (See Figures 37 and 38) graphs (See Figure 39) and of measurement data. It also has an about page with a quick link to the web application (See Figure 40). The mobile application also allows setting alert parameters and lower and upper bounds on said parameters (See Figure 41).



Figure 33 Mobile Splash Page

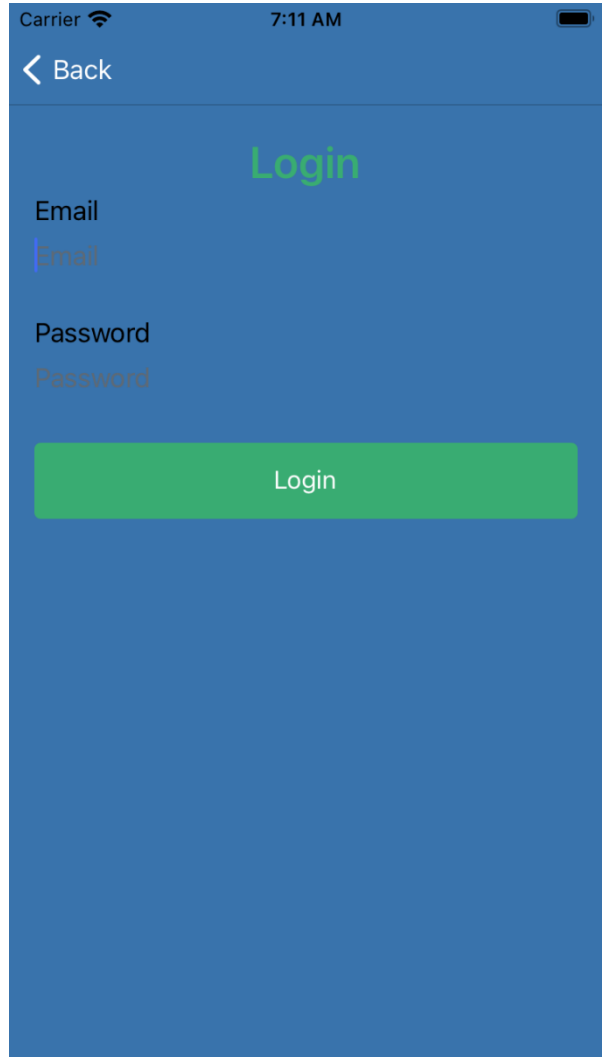


Figure 34 Mobile Login Page

Carrier 7:10 AM

Menu Tables

Tank

Test Device

Timeframe

Last 24 Hours

Date and Time	Measurement
11/8/2020 12:05:00 PM	167.2
11/8/2020 12:00:00 PM	167.2
11/8/2020 11:55:00 AM	167.2
11/8/2020 11:50:00 AM	167.2
11/8/2020 11:45:00 AM	167.2
11/8/2020 11:40:00 AM	167.2
11/8/2020 11:35:00 AM	167.2
11/8/2020 11:30:00 AM	167.2

< O2 Reduction >

Figure 37 Mobile Tables (O2)

Carrier 7:10 AM

Menu Tables

Tank

Test Device

Timeframe

Last 24 Hours

Date and Time	Measurement
11/8/2020 12:05:00 PM	6.83
11/8/2020 12:00:00 PM	4.15
11/8/2020 11:55:00 AM	0.0
11/8/2020 11:50:00 AM	4.26
11/8/2020 11:45:00 AM	0.696
11/8/2020 11:40:00 AM	5.851
11/8/2020 11:35:00 AM	0.965
11/8/2020 11:30:00 AM	3.35

< pH >

Figure 38 Mobile Tables (pH)

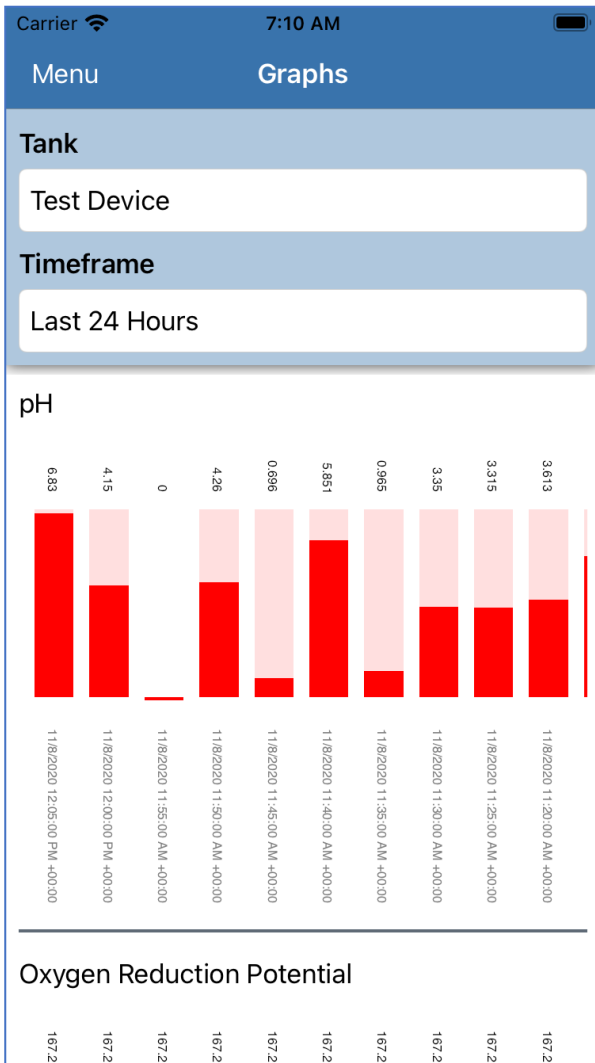


Figure 39 Mobile Graph Page

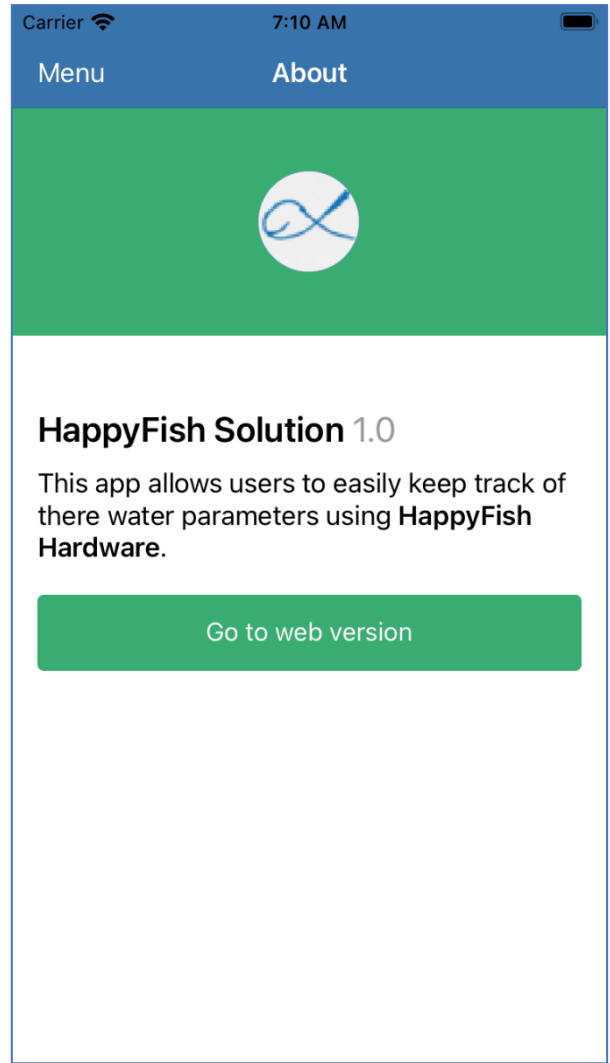


Figure 40 Mobile About Page

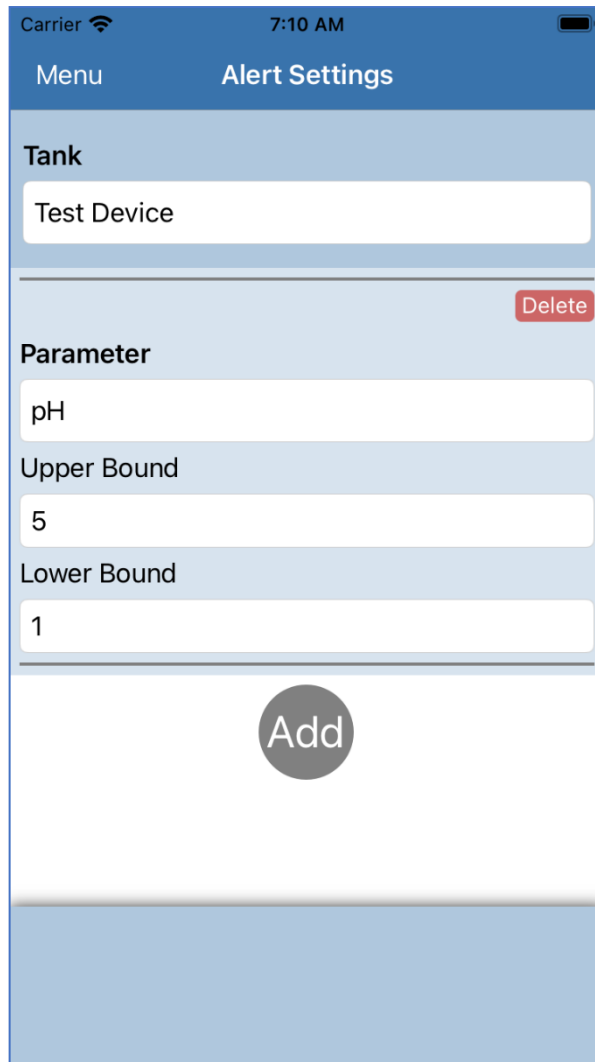


Figure 41 Mobile Alert Parameter Page

4.2 Evaluation

Evaluation of the various systems is based on the ability to efficiently collect and analyze specific water quality parameters. Specifically,

- Data Collection
 - Ability to test the needed parameters
 - The accuracy of the tests
 - How affordable the collection system is
- Data Analysis
 - Ability to access raw data
 - Ability to view historical data
 - Data alert functionality and features
 - Interface usability

The evaluation covered the three different solutions on the aforementioned areas and is detailed in Table 1. The Hach, YSI, and custom solution all had different areas that they excelled in.

Each solution was evaluated on expandability and accuracy of many different parameters, but the focus is on dissolved oxygen, pH, oxygen reduction potential, conductivity, and temperature because these are the most common across the needs of aquaculture research and commercialization.

The Hach solution excelled in the data collection requirement and placed second overall. It's hardware is able to interface with many different sensors and also has quite good accuracy with these sensors. However, the expandability means that much time and money was put into this solution and equates to a massive decline in affordability. The system is the second most accurate but is over twice the cost of YSI and over six times the cost of the custom solution for the same basic parameters. The Hach does have excellent access to data visualizations and alerts in the form of SMS and email. The interface seems well thought out and is modern web application that can be used on desktop and mobile devices.

The solution from YSI comes in last place in the detailed comparison when judging on data collection and analysis. It's poor parameter selection along with its relatively high price makes it hard to recommend to aqua-culturists. Although it does offer the basic parameter set mentioned above its accuracy in these parameters is less than the Hach or custom solution. While it does make up for it in price. Compared to the Hach its price to offering/performance is on par. It gives access to data through its native desktop and mobile application but does not allow users to download raw data. It has an option to give alerts through SMS. The custom solution has the basic parameters covered with the ability to add a few more. The accuracy and price of the probes far better than the other two options. It gives access to data on a web application and native mobile applications. It also allows for downloading CSVs for ease of analysis by researchers. It also gives email and push notifications when measurements are out of bounds.

		Solution		
		Hach	YSI	Custom
Requirements	Parameters	10	4.2	5
	Dissolved Oxygen	10	10	10
	pH	10	10	10
	Oxygen Reduction Potential	10	10	10
	Conductivity	10	10	10
	Temperature	10	10	10
	CO2	10	0	10
	Nitrate	10	0	0
	Orthophosphate	10	0	0
	Turbidity	10	0	0
	Organic Load	10	0	0
	Sludge height	10	0	0
	Ammonium	10	0	0
	Accuracy	8.5	7.2	9.3
	Dissolved Oxygen	8 (±0.1 mg/L)	7 (±0.2 mg/L)	10 (±0.05 mg/L)
	pH	8 (±0.01)	6 (±0.2)	10 (±0.002)
	Oxygen Reduction Potential	10 (± 0.1mV)	5 (±20 mV)	8 (±1mV)
	Conductivity	8 (±2%)	10 (±0.5%)	8 (±2%)
	Temperature	(N/A)	8 (±0.2°C)	10 (±0.1°C)
	CO2	(N/A)	0	10 (±3%)
	Nitrate	10	0	0
	Orthophosphate	10	0	0

Turbidity	10	0	0
Organic Load	10	0	0
Sludge height	10	0	0
Ammonium	10	0	0
Affordability	2	8.5	10
Initial purchase	2 (\$12153)	8 (\$5000)	10 (\$2000)
Subscription fees per month	2 (~\$500)	9 (~\$100)	10 (\$75)
Access to data	10	10	10
Access to raw data	2	2	10
Alert functionality	6.7	3.3	6.7
SMS	10	10	0
Email	10	0	10
Push Notification	0	0	10
Interface Usability	8	8	8
Total	47.2	43.2	59.0

Table 1 Solution Comparison Table

Chapter 5: Lessons Learned

There were many roadblocks when pursuing this capstone project. The capstone began as a hackathon project at the UNCW CIE. I ended up not using any of the hardware or software created at the hackathon, but instead used the idea of monitoring aquaculture systems with an IoT solution. This led me down a path of many hours of researching the best hardware and software for accomplishing this task.

In this research, I learned about various microcontrollers like the various models of Raspberry Pi, as well as Arduinos, and various offerings from Adafruit. All of them had pros and cons and I ended up using the Raspberry Pi because of the flexibility of the Linux OS that runs on Raspberry Pi. This choice, however, made it more difficult to interface with the sensors and probes used.

I also originally started this project with a faculty research advisor that was leaving UNCW. This was something that I thought that I could get done before they left, however I was unable to and therefore needed to find a new advisor. During this time, I also decided to take on a full time job as a software engineer and further cut time out of being able to devote to my capstone. In my last year working on my capstone there was a global pandemic which did not allow me to evaluate my project at the aquaculture research facility. The plan to get feedback from my project and evaluate it on that basis forced me to rethink the assessment of completion of the project.

My decision to make a web application, iOS, and Android application further slowed down completion time. I am glad I decided to pursue all three because I was able to utilize many

different technologies during this process, and although I haven't mastered any particular one during this project I've learned a lot.

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