Tadpole
Aquatic Monitoring and Automation System
Finals Documentation - Addendum

Presented for

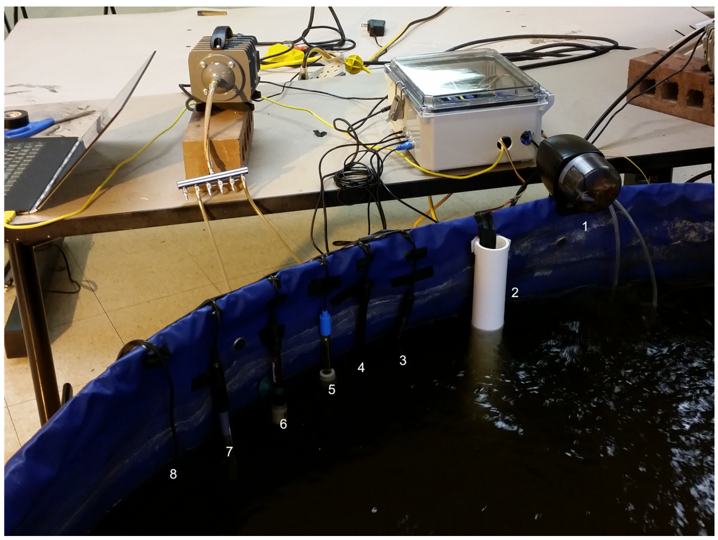
Samsung's Maker's Against Drought Challenge

by

INTEGRATED SYMBIOTICS

1.0 Preface

The purpose of this document is to detail the improvements and progress made by the Integrated Symbiotics (IS) team on its Tadpole Aquatic Monitoring and Automation System (AMAS) unit during the Maker's Against Drought finalist period. This document is an addition to the Technical Document submitted during the general submission period titled *Tadpole Aquatic Monitoring and Automation System*.



Tadpole AMAS

The Integrated Symbiotics team has set out to accomplish three goals during the Finals period to increase our probability of success:

1. Further develop the Tadpole AMAS as a fully functional and reliable product;
2. Fully utilize the Artik platform to the extent of its capabilities; and
3. Generate new ideas that impact those affected by the world water crisis, especially by reducing the entry barrier for use of water-saving technology.

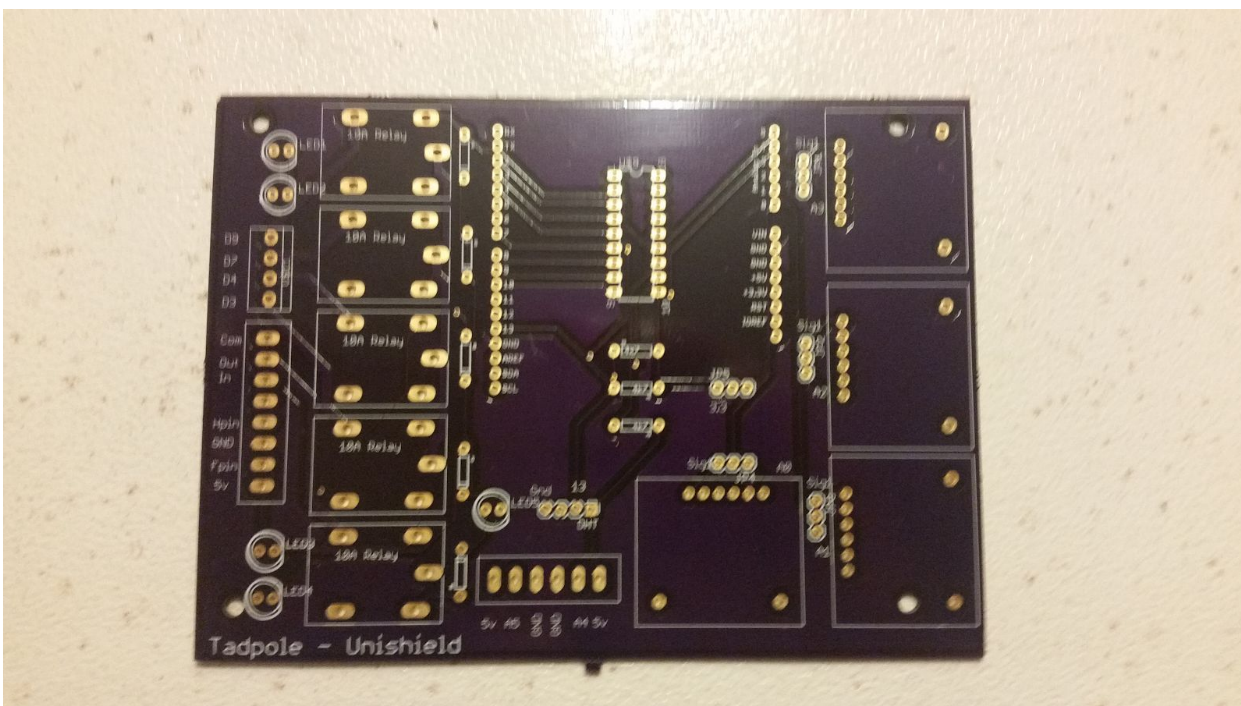
Many of the improvements we chose to undertake are documented in the Technical Document under section 4.1: Continuing Engineering. These additional improvements are presented in the following. All improvements have been made by the IS Tadpole team, comprised of Nicholas Renner, Tyler Rivera, and Joshua Meyer.

2.0 Hardware Modifications

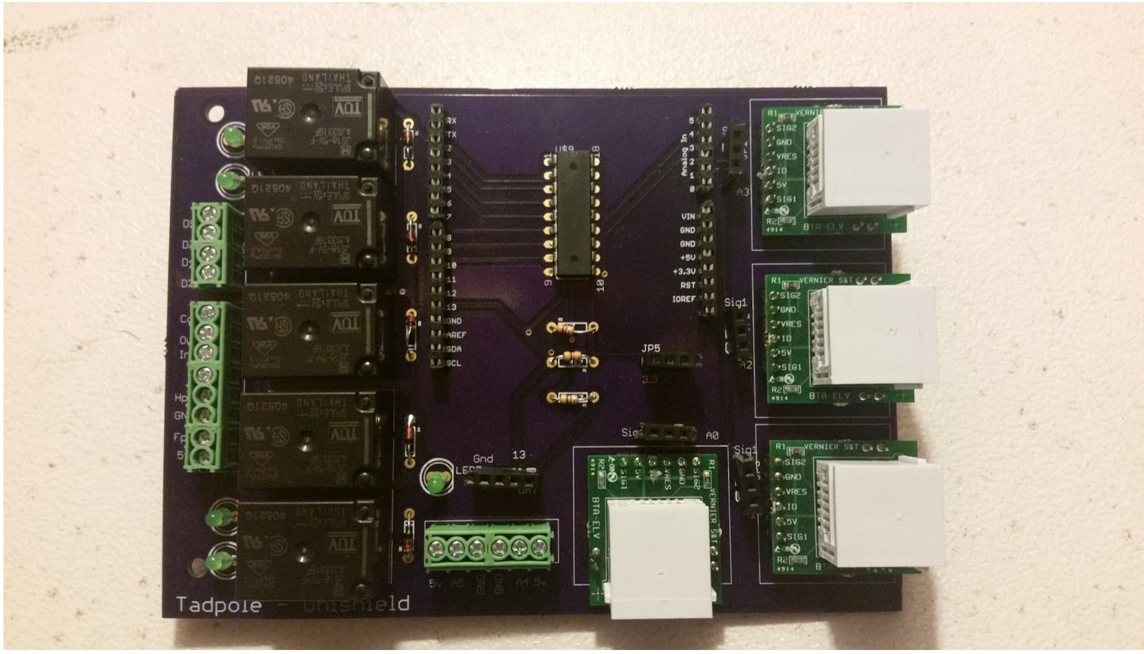
2.1 Shield Re-Engineering

The original Tadpole prototype utilized an additional Arduino Uno, fitted with the Tadpole Monitoring Shield, which connected the sensor suite to the Artik for system monitoring. A second shield, Tadpole Actuator Shield, was fitted on the Artik's native microcontroller ports to control the fish feeder and electrical relays. These both utilized serial communication and used the PySerial library to integrate with the Tadpole's Python backbone located on the Artik board. This caused two problems. First, the connection was unreliable and lossy, and furthermore it failed to utilize the Artik to its full capabilities as an IoT controller.

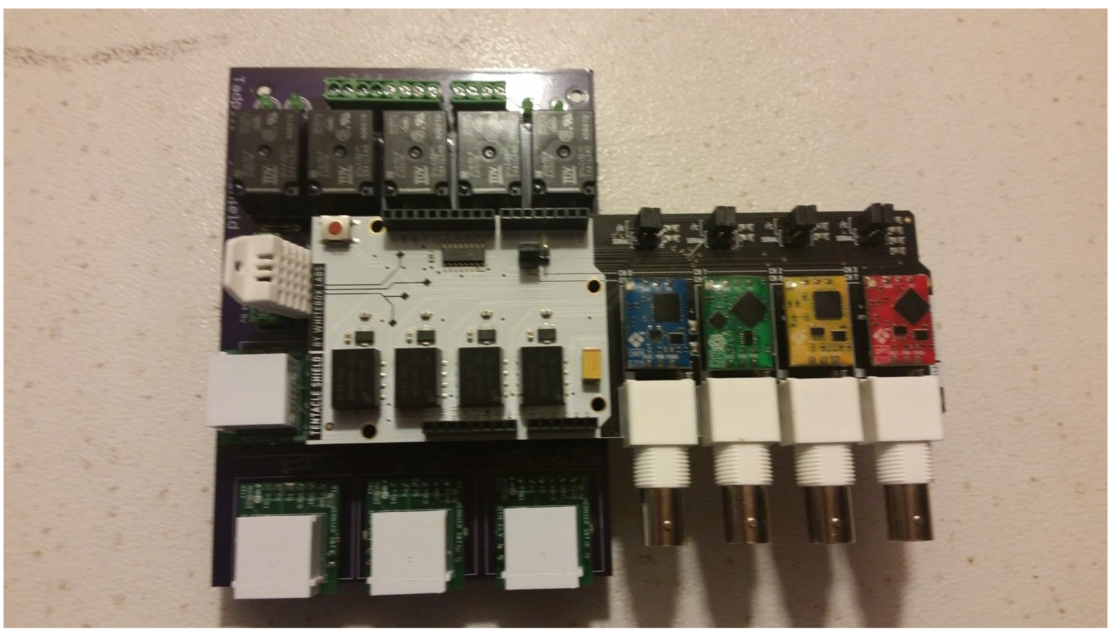
For the finals, we aimed to create a single shield to be retrofitted on the Artik's microcontroller that would control both monitoring and actuator functions. This shield, dubbed the Tadpole Unishield, seamlessly integrates all the hardware for communication with the Artik board via General purpose input/output (GPIO) and inter-integrated circuit (I2C). The shield was custom-designed and fabricated. Pictures of the PCB, Unishield, and the complete Tadpole shield system are shown below, as well as the complete Unishield schematic.



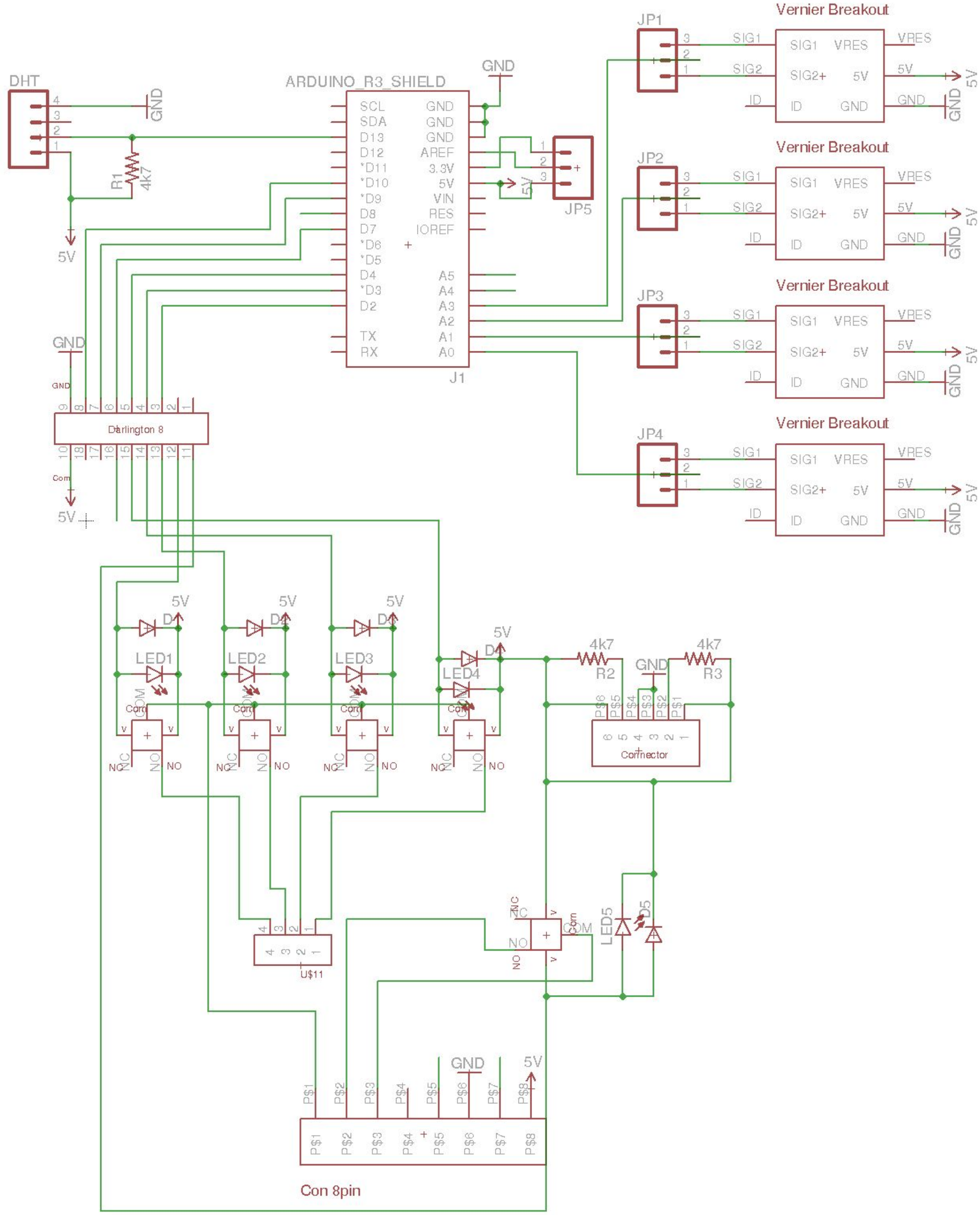
Tadpole Unishield PCB Board



Tadpole Unishield



Tadpole Unishield with Tentacle Shield and DHT



Tadpole Unishield Schematic

The components of the Tadpole Unishield are detailed below:

Tadpole Unishield

Monitoring

- Via GPIO
    - Air Temperature and Humidity - DHT22
    - Water Temperature - DS18b20
    - Water Level - Milone eTape
    - Ion Concentrations - Vernier ISE's
        - Probes for Nitrate, Ammonium, Potassium, Calcium
- Via I2C
    - Water Quality - Atlas Isolation Shield
        - Probes for pH, Dissolved Oxygen, Oxidation-Reduction Potential, Total Dissolved Solids

Automation

- Via GPIO
    - Fish Feeder control - AquaChef Fish Feeder
    - 4 Electrical Relays for 120 VAC
        - Main Pump, Air Pump, Lighting, Heating
    - 1 Electrical Relay for 12 VDC
        - Peristaltic Pump

2.2 Peristaltic Pump

A peristaltic pump was added to the Tadpoloe AMAS as an additional improvement. Nutrient delivery is very important in aquatic agriculture systems. Hydroponic systems are completely dependent on the addition of outside nutrients, while aquaculture and aquaponics systems benefit from the addition of nutrients for deficiency correction. Nutrient solutions (such as MaxiCrop) are among the best ways to deal with deficient potassium in systems. Solutions are also the best way to correct for pH when it swings too high or too low.

Our team has added a peristaltic pump to the Tadpole AMAS for liquid nutrient delivery. A peristaltic pump is a rotor that compresses plastic tubing in order to draw liquid from a reservoir and deliver it to a final location. These pumps are useful because the liquid does not contact mechanical components.

3.0 Full Microcontroller Integration

The initial Tadpole AMAS prototype communicated via serial and used the Python library PySerial to read the serial bus and import that information into the Tadpole service. This created some lag time as well as an unreliable connection. At the time of development, this seemed like the best way to communicate between the Arduino platform and the Linux system, but updated documentation regarding the use of the microcontroller's GPIO (through sysfs) and I2C tools have unlocked the full capabilities of the platform.

3.1 Monitoring

The monitoring controls to accumulate sensor readings are handled via General-purpose input/output (GPIO) and inter-integrated circuit (I2C). Communication from the sensor suite is now done via a Python read service that transmit JSON data to the full Node.js Tadpole-service.

3.1.1 GPIO

Raw voltage is converted to readings for all the Vernier ISE's and the eTape water level meter. The Tadpole takes these raw voltage measurements using the Artik Analog Digital Controller (ADC) interface through file read commands from Python. These values are converted to voltage using the following formula provided by Artik: Voltage = in_voltageX_raw * 2 * 0.439453125 mV. The voltage is then translated to the corresponding readings for the sensors.

Readings for the DHT22 and DS18b20 sensors were first attempted to be taken by adapting C libraries for each sensor for use with the Artik. Since no libraries for Artik pre-existed, this was no small task. The library adaptation would use the technique of "bit-banging" to read the bits transmitted by the sensor. The most difficult aspects of this adaptation arose from (i) the different clock times between Artik and an Arduino, and (ii) the fact that memory is used for multiple processes, which could interfere with a time-sensitive data stream.

Eventually, the sensor readings were taken by using the Arduino DHT and DS18b20 libraries, which were compiled for Artik using the Arduino IDE. The generated ELF executable is called as a subprocess by Python, and the data is parsed to the program. This technique was not only easier, but used the pre-built Arduino functionality of the Artik to a fuller extent.

3.1.2 Inter-Integrated Circuit (I2C)

Originally I2C did not work on the Artik 10 version 3.1. New firmware and data tree files were needed to correct the I2C on the original Artik 10.

Data from the Atlas Scientific probes (ph, ORP, TDS, DO) are taken via I2C using the external bus on the Artik 10 (externally available on connector J27 pins SCL-SDA). This is made possible by the Tentacle sensor shield, which is integrated on the Tadpole Unishield. Values are read using the Python SMBus library. This function calls the correct bus and address to collect data from each sensor.

3.2 Actuators

Relays

The power control functions (main pump, air pump, lighting, and heating) are all triggered via relays on the Tadpole Unishield activating 120 VAC. The peristaltic pump is triggered via a relay on the Tadpole Unishield activating 12 VDC. These relays are turned on and off by a Python script using the GPIO write function. Those scripts are activated via web-socket from the Artik cloud service.

Fish Feeder

The Arduino program for the hacked Aqua Chef fish feeder was re-written in Python using the Artik's GPIO write and read functions. The motor is activated via GPIO write, and then the home sensor is read using GPIO read. When the home sensor reads LOW, the motor turns the fish feeder, and the motor stops once the home sensor reads HIGH. This program is run via web-socket from the Artik cloud service.

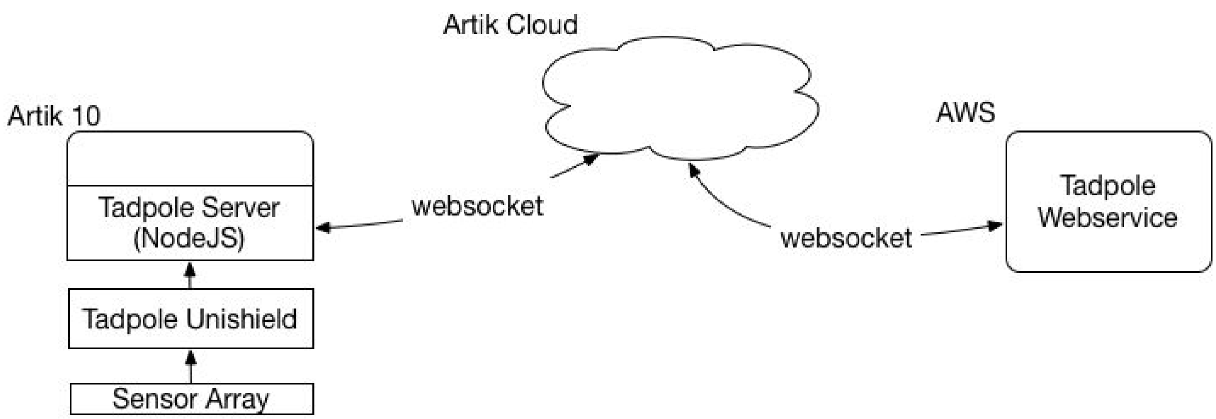
4.0 Software Updates

4.1 Node.js for Server and Web-service

After using a Python backbone for most of the infrastructure in the initial submission, the Tadpole team has switched to Node.js. The key reason is that we discovered that IoT applications/devices are heavily event-based. We realized that an event-based asynchronous framework like Node would lend itself well to the project. The Tadpole Server located on the Artik 10 and the Tadpole Web-service located in Amazon Web Services (AWS) were ported to Node.js, which simplifies many processes.

4.2 Artik Cloud Implementation

The Artik Cloud platform officially launched around the time of the general submission date, so it was not included in the initial submission. The Tadpole Server running on the Artik 10 and the Tadpole Web-service running on an Amazon Web Services EC2 instance establish a secure websocket connection to the Artik Cloud platform. In this project, we rely on the Artik Cloud to act as a central repository for all data transmitted from the Tadpole, as well as a means of managing state across the device and our web UI.



Artik Cloud Architecture

Data is collected from the sensor array through the Tadpole Unishield, as relayed in Section 3.0 Full Microcontroller Integration. The Tadpole Server was ported to Node.js and now communicates to Artik Cloud for both data and actions through websockets. The example payload for data transmission is included below. It follows the format established by the manifest defined in the Artik Cloud “Tadpole AMAS” device type.

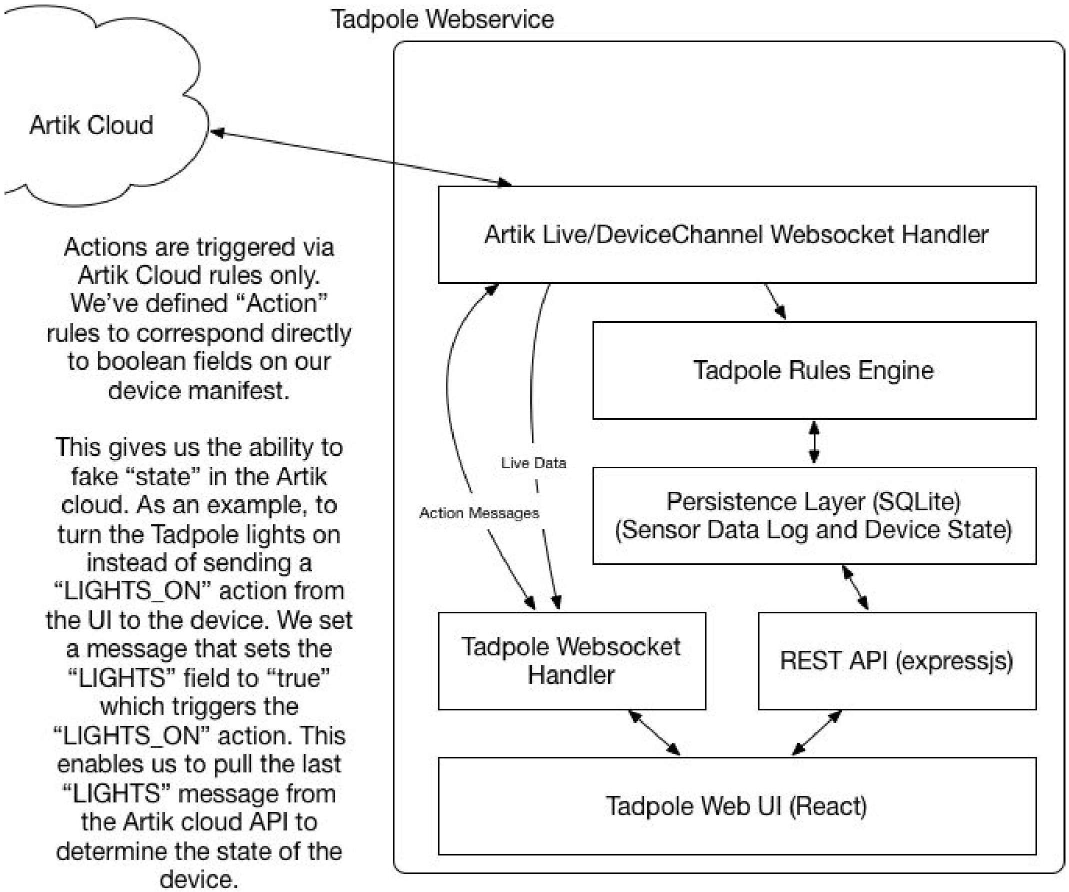
Example Payload <json>


```json
{
  "REDOX_POTENTIAL": 341.52587890625,
  "TDS": 1017.49365234375,
  "WATER_LEVEL": 4.883176803588867,
  "HUMIDITY": 66.72319030761719,
  "NITRATE": 89.33629608154297,
  "CALCIUM": 128.83953857421875,
  "PH": 8.635509490966797,
  "WATER_TEMP": 41.261837005615234,
  "DO": 10.874696731567383,
  "POTASSIUM": 148.8719940185547,
  "AMMONIUM": 2.606841564178467,
  "AIRTEMP": 29.464618682861328
}
```

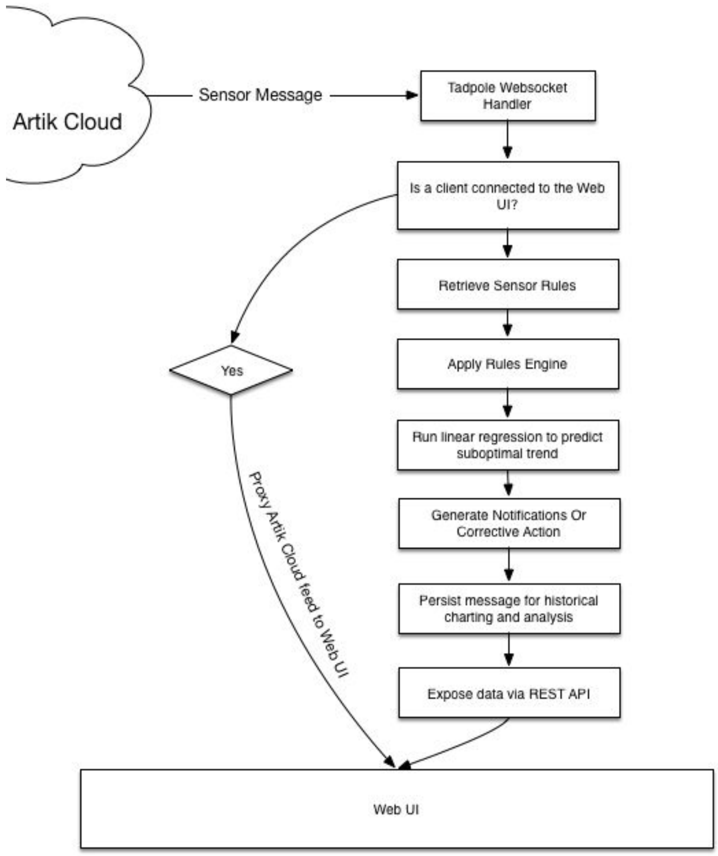

Example Payload

4.3 Web-service Architecture

The Tadpole Web-service connects the information from the cloud via websockets to the UI and our own persistent store. The Sensor Data Flow diagram shows the flow of data from the Artik Cloud through the Tadpole web-service -- driving both the real-time dash (if a user is connected) and piping the data through our rules engine (generating notifications via application of optimum environment levels rules to sensor data) and predictive algorithm, and ultimately persisting that data to our back-end database. The REST API provides endpoints which describe actions, notifications, sensor reads, established routines, sensors (including their associated rules), and device state. These endpoints drive the web interface for things such as notifications and historical analysis. When a user is connected, real-time data and action items are sent to the Tadpole websocket handler which engages directly with the React UI. When a state change occurs (such as “Lights On”), the change is synced across the front-end, the Artik Cloud, and the Tadpole itself.



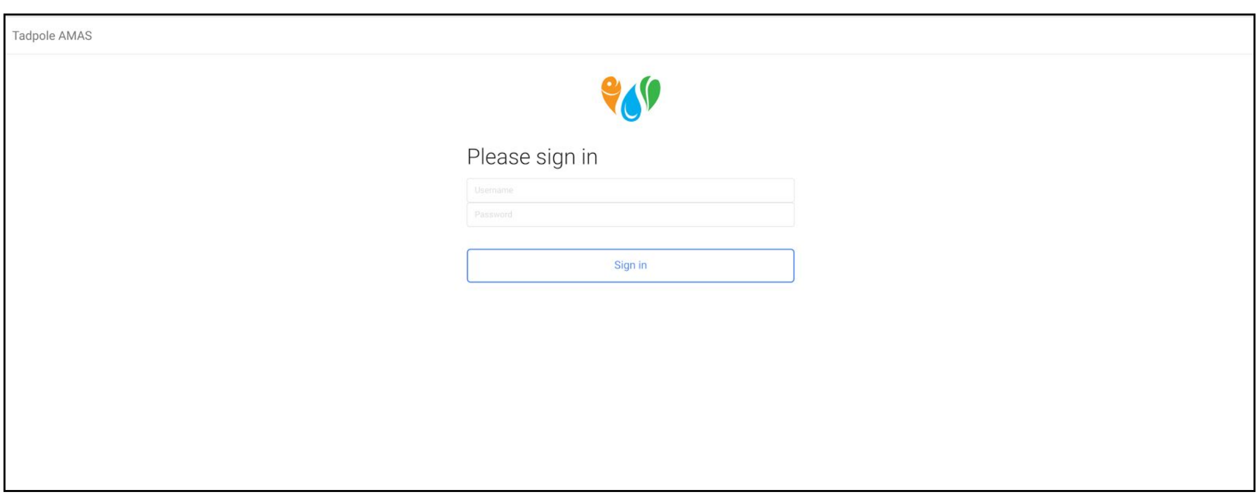
Web-service Architecture



Sensor Data Flow

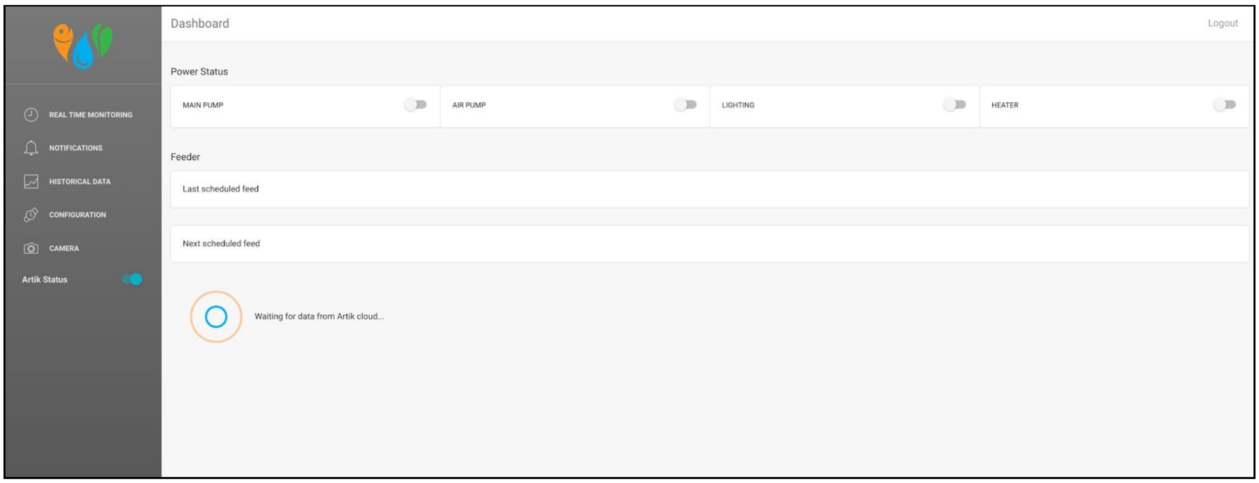
4.4 User Interface

The user interface is configured for authentication and user login. This adds security to the Tadpole AMAS system so that only the valid user can update settings and routines.



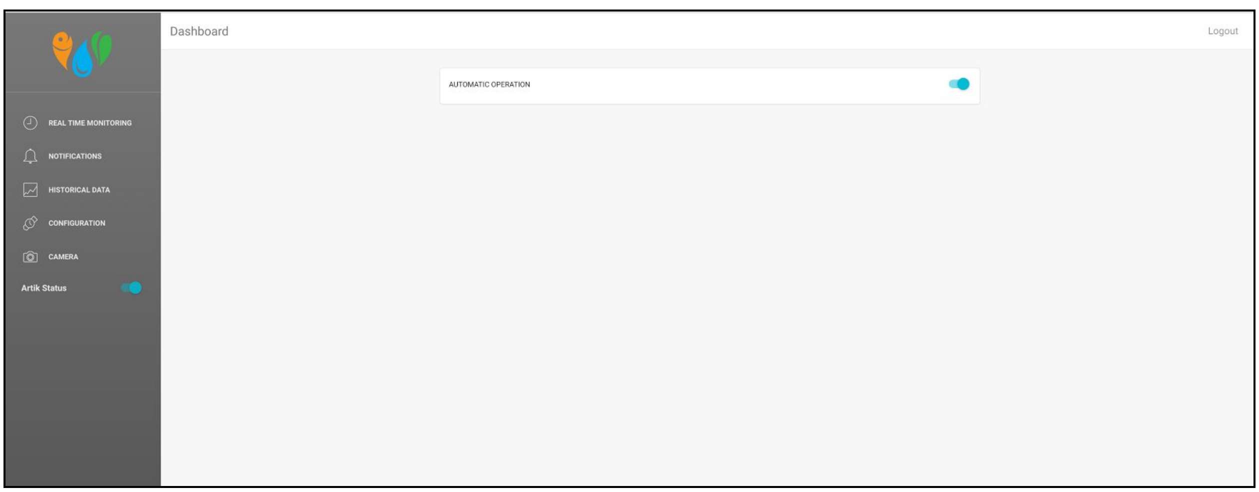
Tadpole Login Screen

The user interface has been updated to now include a loading graphic while waiting to receive the real-time data (which is now truly real-time due to the Cloud implementation). In addition, the slide bars on the dashboard now can directly turn electronic components on and off via toggling the UI graphic.



Tadpole Dashboard

Automation functions can now be toggled on and off via a slide bar on the Configuration page.



Tadpole Automation Toggle

The full UI is now fully accessible via mobile, allowing for control from anywhere in the world.

5.0 True Automation via Data Responsive Actuator Control

One of our three main goals was to, “Generate new ideas that impact those affected by the world water crisis, especially by reducing the entry barrier for use of water-saving technology.” It will take a major shift in current agricultural practices to truly embrace recirculating aquatic agriculture and its benefits, namely the greater-than-90% water reduction actualized by these systems. One major incentive to adapt these systems is the potential to dramatically decrease the labor required to grow food. The task of automating systems so that they only need to be checked periodically is clearly in line with that goal.

The IS team decided that making progress toward an entirely automated system would be the best way to take advantage of the Artik’s full capabilities and to demonstrate how it could effect a reduction in labor.

5.1 Prediction Methods

Predictive methods were developed as a first step in creating automation tactics. The mathematical models used here are basic but have room for an expansive amount of growth using ideas such as machine learning. Models were created using historical data from the most recent 12 hours of readings. This was accomplished using linear regression via the least squares method. Future data points are determined using the regression model and the last data point for each sensor. If the next data point goes into a warning zone, corrections will start.

These predictive methods cannot use the Artik Cloud rules engine, because of the nature of the actions. The system needs to wait for any changes to take effect before applying more corrections. This prevents the system from dumping food and nutrients into the system rapidly if problems arise, which leads to dangerous overcorrection.

5.2 Functions

When enabled, the automation function will control the aquaponic system via actuators based on data received while monitoring the system.

Lighting

In automation mode, the Tadpole simulates the available daylight for growth in an average day by turning the lighting unit on at 8AM and off at 5PM.

Main Pump via Water Level

As a safety feature, when the Tadpole detects the water level to be dangerously low, the main water pump is shut off while the system administers a danger notification.

Air Pump via Dissolved Oxygen

When the Tadpole detects that dissolved oxygen levels are low, a warning notification is sent and the backup air pump is activated. Once dissolved oxygen levels normalize, the backup air pump is then turned off.

Fish Feeding via Nitrate

Nitrates accumulate in the system from waste produced by fish after feeding. The fish excrete ammonia, which bacteria convert into nitrate. This makes nitrate levels dependent on feeding frequency. Nitrates are removed from the system by the plants that utilize them to grow.

During normal automation mode operation, the fish-feeder is activated once a day to feed the fish in the aquaponics system. When the Tadpole detects nitrate levels below 20 ppm, feeds are increased to twice per day. When nitrate levels rise above 80 ppm, a notification is sent and feeds are stopped until the nitrate levels drop back into the appropriate range.

Heat Control via Water Temperature

The Tadpole monitors water temperature via the DS18b20 probe. When water temperature drops below 70F, a warning notification is triggered and the heating unit is activated via its relay. When water temperature returns to a safe range, the heating unit is turned off.

Potassium Solution via Potassium Concentration

The Tadpole monitors potassium concentration via the Vernier Potassium ISE. In automation mode, potassium solution as MaxiCrop fertilizer solution is administered once per week. When potassium levels are low, a notification is triggered and potassium is administered once per day until levels come back to a normal range.

5.3 Baseline

The following is the baseline function of the automation setting:

- Lighting
  - On 8AM
  - Off 5PM
- Main Pump
  - Starts on
  - If low water level triggers Danger notification, turn main pump off
  - When no longer in Danger, turn main pump on
- Backup Air Pump
  - Starts off
  - If low dissolved oxygen triggers Warning notification, turn air pump on
  - When high dissolved oxygen triggers Warning notification, turn air pump off
- Fish Feeder
  - Base: Feeds two feeder rotations, once per day
  - If low nitrate triggers Warning notification, increase feedings to twice per day
  - If high nitrate triggers Warning notification, halt daily feeding
- Heat Control
  - Starts off
  - If low water temperature triggers Warning notification, turn heater on
  - When no longer in Danger, turn heater off
- Nutrient Solution Delivery
  - Deliver 100 mL nutrient solution via peristaltic pump once per week
  - If potassium triggers warning, dispense solution once, then wait one day to determine if further correction is necessary

6.0 Conclusion

The state of California has recently experienced one of the worst droughts in U.S. history. California's current drought has been billed as the driest period since the state began recording rainfall. A mega-drought would have catastrophic environmental effects, and the potential economic and social repercussions of such a situation are both ominous and unpredictable in a world almost completely dependent on commercial agriculture.

Globally, the agricultural sector consumes about 70% of the planet's accessible freshwater, more than twice that of industry (23%) and dwarfing municipal use (8%). In California alone, farmers use 80% of the water consumed by people and businesses in an average year, according to the State Department of Water Resources.

The Tadpole AMAS can help reduce the barrier to entry for individuals looking to adopt agricultural technologies, such as aquaponics and its constituents, hydroponics, and recirculating aquaculture. These technologies are proven to reduce the water consumption needed to grow food by over 90% from that of traditional methods.

More background information on aquaponics and the water crisis can be found in Section 1.0, Introduction, of the Technical Document submitted for the first round of the Maker's Against Drought competition.

The Tadpole AMAS is a perfect candidate to receive the Maker's Against Drought competition award. During the finals period, our project team successfully integrated our main goals by performing the following:

Further develop the Tadpole AMAS as a fully functional and reliable product.

- The design and implementation of the Tadpole Unishield created a compact, fully integrated hardware interface from which all operations now occur.
- Switching to Node.js simplified the server and Tadpole-side software platform by introducing an event-based asynchronous framework.
- The updated user interface provides optimal user experience by providing a means for the user to fully control the unit with a smooth learning curve.

Fully utilize the Artik platform to the extent of its capabilities.

- Implementing the Artik Cloud showcases Samsung's service, which efficiently manages all data transfer from unit to web interface. The rules engine easily handles data generated by the Tadpole.
- By using both digital and analog input and output through the Artik's GPIO capability, we have simplified the processing of all actions and sensors from the Artik platform. Switching relays, running motors, and reading sensors are now all possible through the Tadpole AMAS.
- Using the Artik's I2C capability allows for easy reading of substantial sensor arrays.

- The integration of Arduino capabilities on the Artik makes it easy to include libraries pre-written for the Artik and to use the processor to emulate 8-bit functions.

Generate new ideas that impact those affected by the world water crisis, especially by reducing the entry barrier for use of water-saving technology.

- The addition of nutrient delivery functions allows for even more hands-off operation of agricultural systems.
- Automation is the next step in improving recirculating aquatic agriculture and adopting its tremendous water-reduction capabilities. It will take a major shift in current agricultural practices to truly embrace recirculating aquatic agriculture and its benefits, namely the greater-than-90% water reduction actualized by these systems. Decreasing the labor required to grow food, so that the process only needs periodic maintenance, will increase efficiency while also reducing natural resource consumption. By advancing toward an entirely automated system and fully utilizing Artik's capabilities, we can demonstrate the type of efficiency and incentivize adoption of aquatic agriculture technology.

The Tadpole AMAS team thanks Samsung for the opportunity to participate in the Maker's Against Drought competition. We believe that our invention has the capability to change the world, solving the water crisis with innovation.