Team 31
Final Design Review

UAV and Lora Network Based Lake Champlain Water Quality Sensing and Mapping

Team Members:
Nathaniel Cassidy (Nathaniel.Cassidy@uvm.edu)
Abdoulaye Ira (Abdoulaye.Ira@uvm.edu)
Andrew Knowlton (Andrew.Knowlton@uvm.edu)
Kaseya Xia (zxia@uvm.edu)

Client: Dr. Tian Xia, Dr. Dryver Huston

Mentor: Dr. Tian Xia, Dr. Dryver Huston

Table of Content

Disclaimer Form

SEED Program Disclaimer

Dear Dr. Tian Xia and Dr. Drvyer Huston,

Thank you for participating in the SEED program. The efforts of our team have resulted in prototype hardware, called the Device, and associated documentation. The Device and its' documentation is presented "as is" without any guarantees or warranty. In association with the Device, UVM provides no warranties of any kind, either expressed or implied, including but not limited to warranties of merchantability, fitness for a particular purpose, of title, or of non-infringement of third party rights. Use of the Device is at the end users risk. In receiving the Device, the Client agrees to indemnify UVM, its agents, students and employees from any and all liability, claims, causes of action or demands of any kind and nature that may arise in connection with this Device.

SEED Team 31 Student Names and Signatures

Ziyi Xia (Apr 25, 2020)

Student – Kaseya Xia Date

Nathaniel Cassidy (Apr 25, 2020)

Student – Nathaniel Cassidy Date

Abdoulaye Ira (Apr 26, 2020)

Student – Abdoulaye Ira Date

Andrew Knowlton (Apr 26, 2020)

Student – Andrew Knowlton Date

Clients Name and Signature

Tian Xia

Tian Xia (Apr 26, 2020)

Client – Tian Xia Date

Dryver R Huston

Client – Drvyer Huston Date

Formal Memo

We would like to thank client and mentor Dr. Xia and Dr. Huston for their support in this project.

We would like to thank SEED program head Prof. Dustin Rand for their organization of this program.

We would like to thank UVM CEMs Technical Support Tim Raymond for their support for gateway installation.

We would like to thank IoT associates AJ Rossman and Eric Hall for their support for the Lora transmission system.

We would like to thank UVM IEEE for their support for providing the test drone.

We would like to thank UVM Rubenstein College Prof. Clayton Williams for their research in bacterial sensors.

Below is the list of deliverables that were agreed to in the Project Scope statement.

File	**Location**	**Status**	**Description**
Final Render	Technical Documents/Final Render	Complete	Images of final design render
Part Drawings	Technical Documents/Parts Drawings	Complete	Part Drawings, as well as assembly drawings, for manufacturing
PCB	Technical Documents/PCB	Complete	PCB shield design
Wiring diagram	Technical Documents/Wiring diagram	Complete	Wiring diagram for electrical system
Solidwork Part and Assembly Files	Technical Documents/Solidworks Files	Complete	All the necessary files for the Solidworks model
Schematics	Technical Documents/Schematics	Complete	Schematics for electrical system

Arduino Code	Technical Documents/Code	Needs improvements	Arduino Code for all the sensors

Abstract

Multiple methods have been used to measure the Lake Champlain water quality due to the presence of bacteria. Current methods are slow and not cost effective if large areas need to be sampled. Team 31 is proposing a water sampling UAV with LoRa based real-time transmission system to measure the water quality. Individual systems have been built and tested to be working well. However, the global pandemic intervention stopped the team from putting everything together and performing actual field testing. The major impacts also include the limitation of the Things of Network bandwidth decrease and accessibility to the lab due to the shutdown of University. Future work needed for the project includes re-testing of the transmission system, final product integration, and color map generation with real-time data.

Problem Statement

The majority of beach closures on Lake Champlain are the result of high coliform bacteria. Currently the sampling of lake water quality is performed by people using boats to collect and test water samples. It can take up to two days for sample analyses to be completed, so the worst of conditions often pass before results are available. Team 31 is going to design a water sampling system to test and provide real time mapping of the Lake Champlain water quality. This project provides a concept proving basis for the clients to acquire more funding to realize this design. The commercialization of this design will provide timely information for the environmental department to make decisions on allowing recreational use of the lake. General water monitoring on a weekly or daily basis is possible at a lower price than the current method.

Working Design Concept

This design specifically hangs the sensors from the sensor box, and into the water. Connecting the sensors and the board is a Mini-DIN and the necessary wires for communication. The sensors' wires are connected to the required adapters, and then relayed to the microprocessor. Given the limitation that a drone can safely hover close to the water surface, the hanging wire needs to be at least 4 m long. A hole in the middle of the sensor box is where the male and female Mini-DIN will be placed to connect the sensors and the wire hanging below to the Arduino mega inside the box. This design provides the most efficient battery use among all the designs (Water Collecting Method and Water Landing Method). The drone only needs to hover on top of the water for a short period of time (10 seconds) while the sensor collects data. Then the drone can quickly move to the next sampling spot to collect data again. Thus, it will be able to measure water qualities at more testing spots and create a better map resolution.

Functionality

Figure 1 presents the high level functionality and interface between different systems.

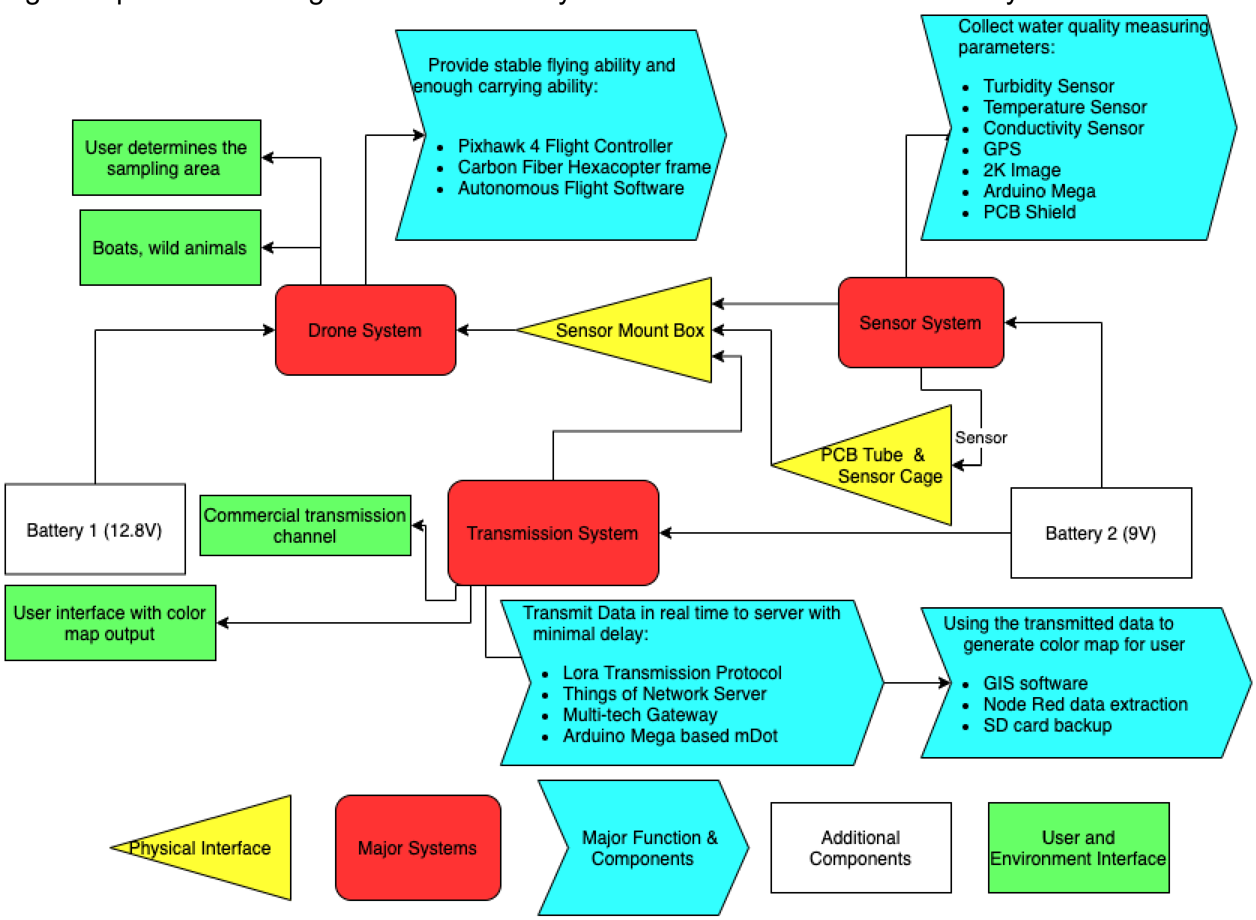


Figure 1: Function Block Diagram

Synchronization

Figure 2 shows the BJT system which will be triggered if the two open leads make contact with water. The voltage through the 50k resistor will be read by the analog pin of the arduino. This mechanism is used to start the data collection cycle. The turbidity, TDS, GPS and camera are all connected with arduino. After triggering, all the sensors will be active and start collecting data. Arduino will process the collected data, send via Lora transmission and also save a copy of the data in the SD card through a SD card module.

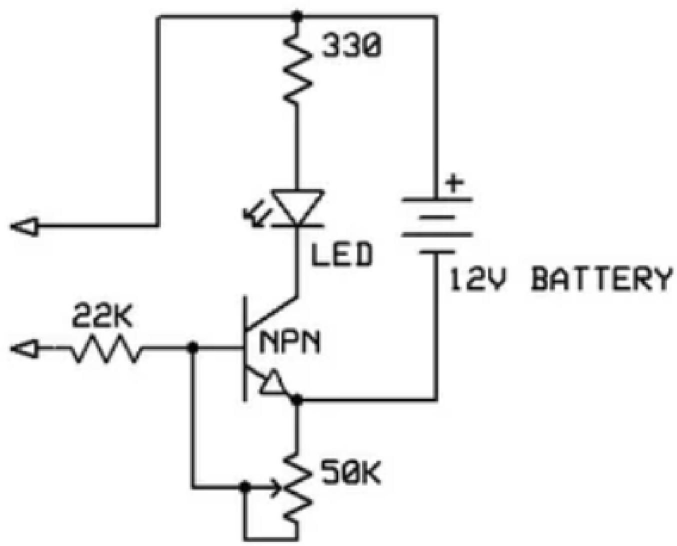


Figure 2: BJT sensor triggering system

Sensor System

The drone is equipped with sensors that are connected to a microcontroller. The sensors are connected via an 8-core wire to the drone, with a length of 5 meters. The sensors are submerged in the water inside a sensor holding unit, providing protection to the sensors. The water depth of the data can be adjusted by turning the height of the sensor cage.
To collect data, the drone will hover over an area and descend to roughly a height of 4 meters above the water. If the sensors become caught in debris or other objects in the water, the entire cable is detachable from the rest of the drone via an 8-pin DIN port. This provides a failsafe from losing the drone due to entangled sensors. The sensors will be submerged for approximately 10 seconds to collect all the data.

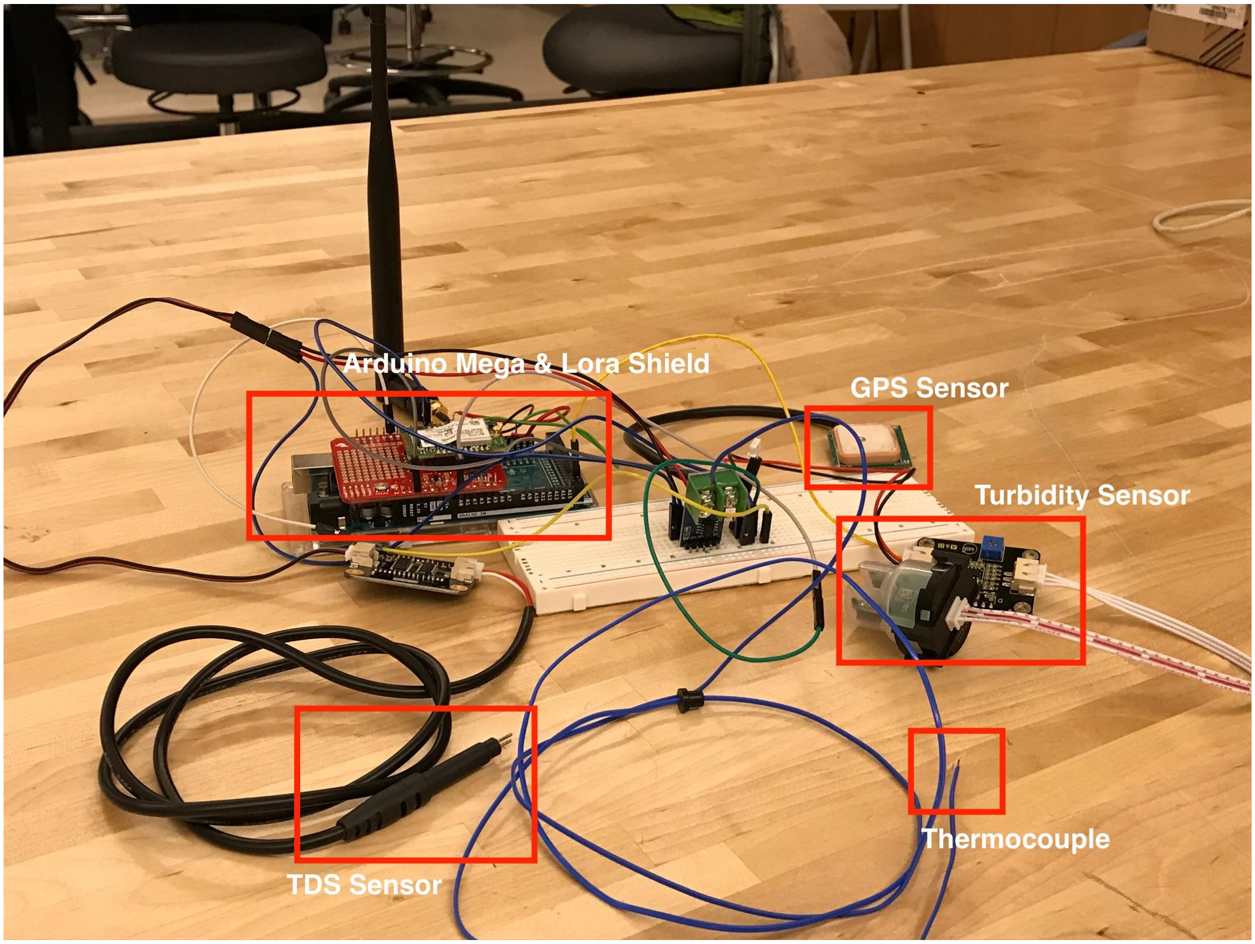


Figure 3: Sensor system with TDS, GPS, turbidity and thermocouple sensors

The sensors are as followed:

- MAX6675 K type Thermocouple Temperature Sensor
  The MAX6675 performs cold-junction compensation and digitizes the signal from a type-K thermocouple.
  Accuracy: +/- 0.25 C

- SEN0189 Turbidity SKU Sensor
  Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particles.
  Accuracy: 1 NTU

- SEN0244 Conductivity Sensor
  TDS (Total Dissolved Solids) indicates how many milligrams of soluble solids dissolved in one liter of water. In general, the higher the TDS value, the more soluble solids dissolved in water, and the less clean the water is. Therefore, the

TDS value can be used as one of the references for reflecting the cleanliness of water.
Accuracy: 20 ppm

- ESP32 Camera Imaging
  ESP32 is a power camera module with integration of Bluetooth and Wi-Fi functions. The camera will be in the sleep mode for most of the time. When the sensors are dipped into the water, the camera will be triggered by one digital pin from Arduino and starts to take pictures. The ESP32 equipes its own SD card and saves pictures with timestamp.
  Quality: 200M Pixel digital camera

- NEO-6M GPS Module
  Baud Rate: 9600
  Sensitivity: -161dBM
  Number of Channels:50
  Update Rate: 1Hz, 5Hz maximum

Working Drone

- Tarot 680 Pro frame
- Motors: Tarot 4006 620kv
- Propellers: Carbon 12x4.5
- Escs: 40 amp
- Battery: 4S 7500mAh
- FrSky Transmitter and Receiver
- Autopilot:
  - PixHawk
    - Autonomous flight
    - Waypoint controlled flight path
  - Loiter accuracy of 1 meter
  - Ultrasonic sensor for altitude sensing
- 3 mile range
- 22 minute flight time
- 2.5kg payload capacity
- Fully autonomous from takeoff to landing

Mechanical Drawing

Figure 4 shows the sensor box CAD model and the sensor box carried by the drone. All the electronics reside in the sensor box with the exception that the Lora antenna sticks out and the GPS sits outside to create more isolation for better GPS accuracy.

Figure 4: Mechanical CAD model

Electrical Schematics

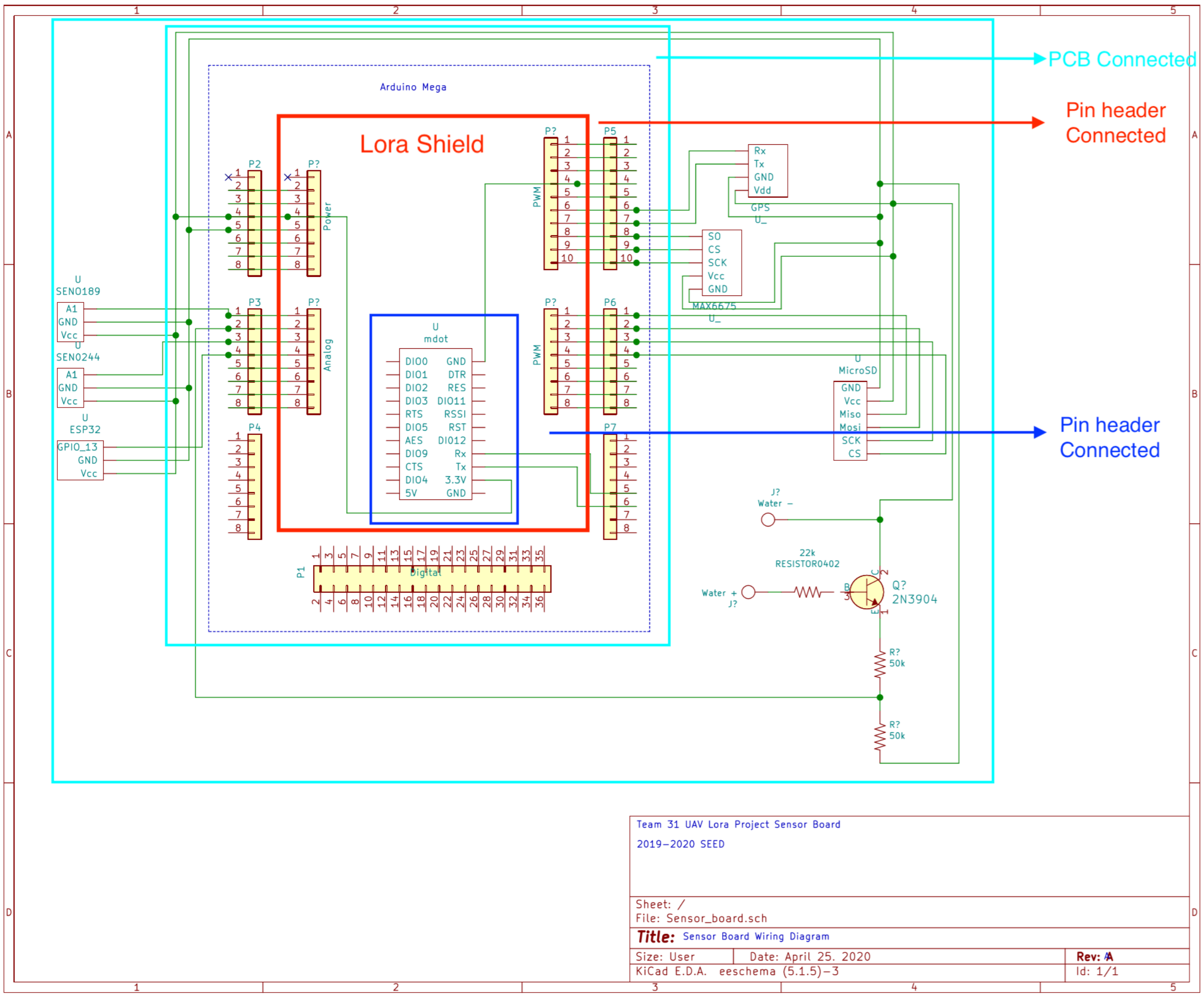


Figure 5: Electrical Schematics with Wiring

Accomplishments

- Measure the temperature
- Measure the turbidity
- Measure the GPS coordinate
- Storage of necessary data on Arduino
- Sense the conductivity
- Transmit data via LoRa
- Gateway installation at Votey, IoT and Generator
- Receive and Upload data (the Gateway)
- Download and save data into a file (Raspberry Pi with Node Red file)
- Lift the sensor system or similar load
- Fly the sensor system or similar load

- Measure the altitude with ultrasound sensor on the drone
- Implemented Fail safe mode
- Implemented emergency breakaway system

Omissions

- Write and Read data from SD card
- Take pictures with the new camera
- Collect data at different depth in water (Optional)
- Color map generation
- Accurate GPS data to 3 meters
    - Currently have 10 meters

Analysis

FEA on Support Arm

A computational solid mechanics simulation was performed using the Abaqus software. This study was performed for the support arm which secures the sensor box to the drone. This is a new analysis and the goal of this analysis is to see how severe loading conditions could affect the arm by looking at how close the resultant stresses are to the yield stress of the material.

Mesh: 16198 elements

Assumptions:

- Maximum load of 19.8 newtons per arm
    - This is twice the weight limit of 2 kilograms from the Engineering Specifications
- Material properties taken from research on 3D printed PLA
    - Yield stress of 19.8 MPa for material with a grid pattern and an infill of 50%
    - Young's Modulus of 3.5 GPa
- Fasteners are not considered because the 3D printed material is much weaker than any fasteners used in production
- The arm is fixed in the cylindrical hole and loaded on what would be considered the bottom of the support

The support arm currently in use is shown in the figure titled “Current Design”. This image shows the contours of the Von Mises stresses in the arm after applying the specified 39.2 newton load.

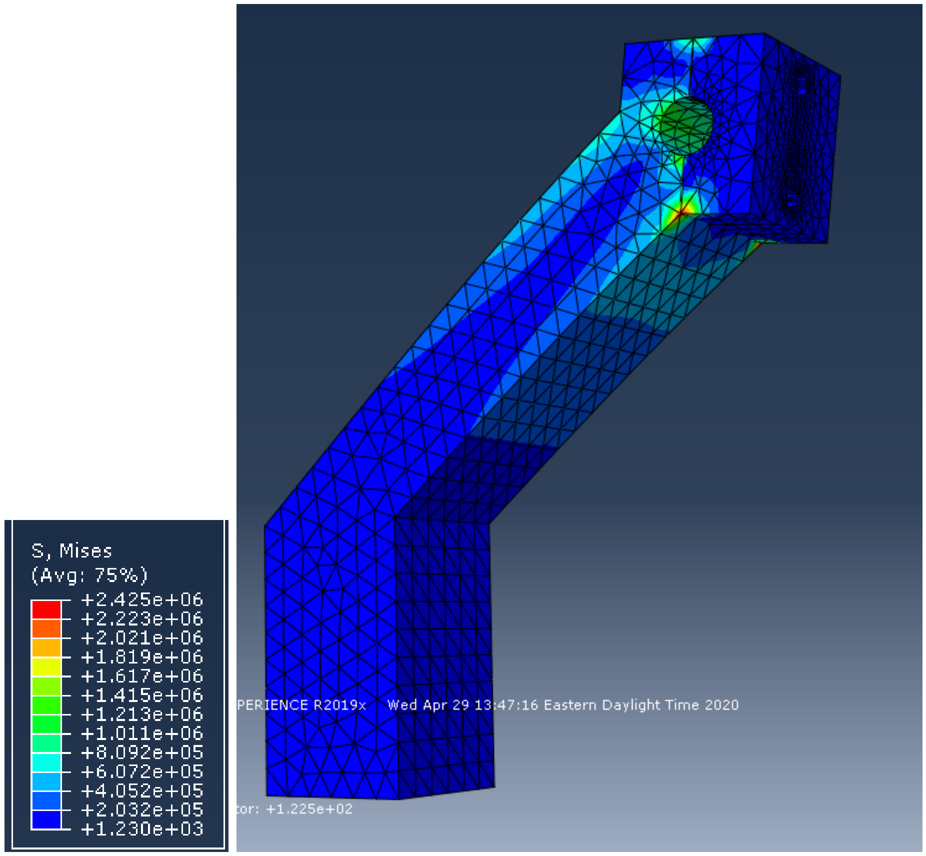


Figure 6: FEA on old arm

The results show that the highest stress levels appear directly below where the arm is fastened to the drone which is to be expected because it is where the cross sectional area is the least. The maximum stress is 2.425 MPa which is significantly less than the yield stress of 19.8 MPa. This indicates a safety factor of around 8. Based on the input conditions and assumptions, the arm will not fail or plastically deform from the sensor box load.

FEA on updated support arm design

The working support arm was determined to be too bulky and used too much material. The new concept for the arm is much thinner and lighter and as an added benefit it can be printed as one part instead of two. The volume of the new arm is 49.546 cubic centimeters as opposed to 115.991 cubic centimeters. This saves 66.44 cubic centimeters of material which is 57% of the original size. The same assumptions are made for this analysis as in previous FEA.

Mesh: 5765 elements

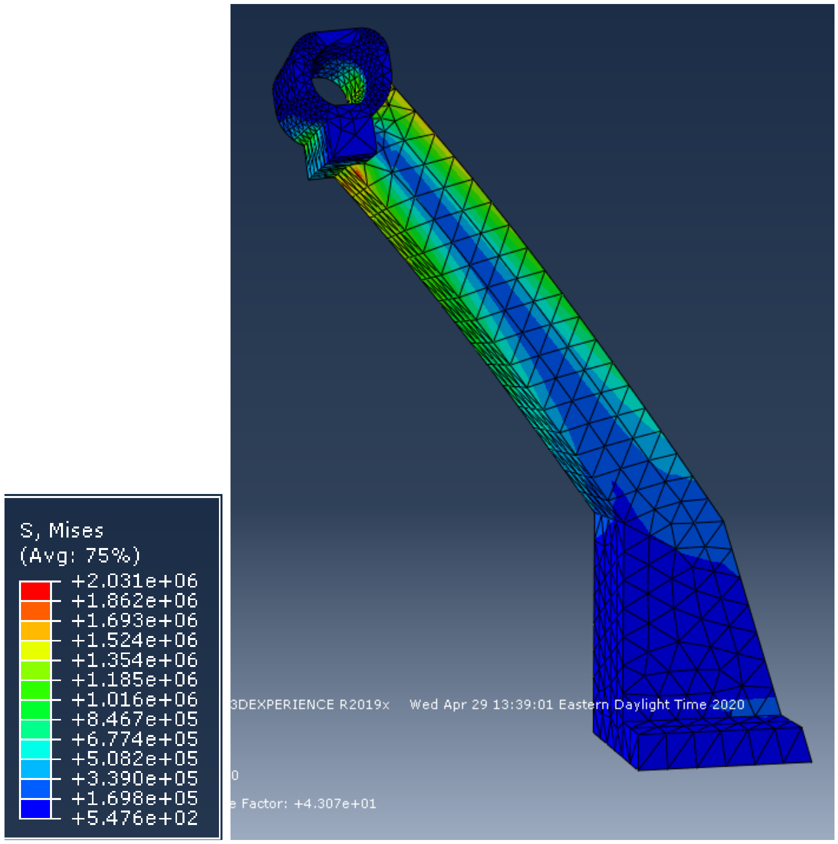


Figure 7: FEA on New Arm Concept

The results of the simulation show that the Von Mises stress in the new design is one order of magnitude less than the yield stress. Once again, based on the input conditions and assumptions this design will not fail. The maximum stress for this design is 2.031 MPa which is less than the maximum stress in the previous design iteration. This design performs better under the same loading conditions and uses less volume and material. The results indicate that an even thinner support could be utilized.

Drone Flight Analysis

The website eCalc.com was used for drone flight performance with the given load of the sensor system. The website has the ability to calculate multiple flight and power use characteristics of the drone based on components and other environmental conditions.

The specific drone componentry was added to the calculator, as well as conditions of flying in Burlington, VT on a summer day. The Drone Payload was added to this measurement, with a total extra weight of the sensor system of 530g.

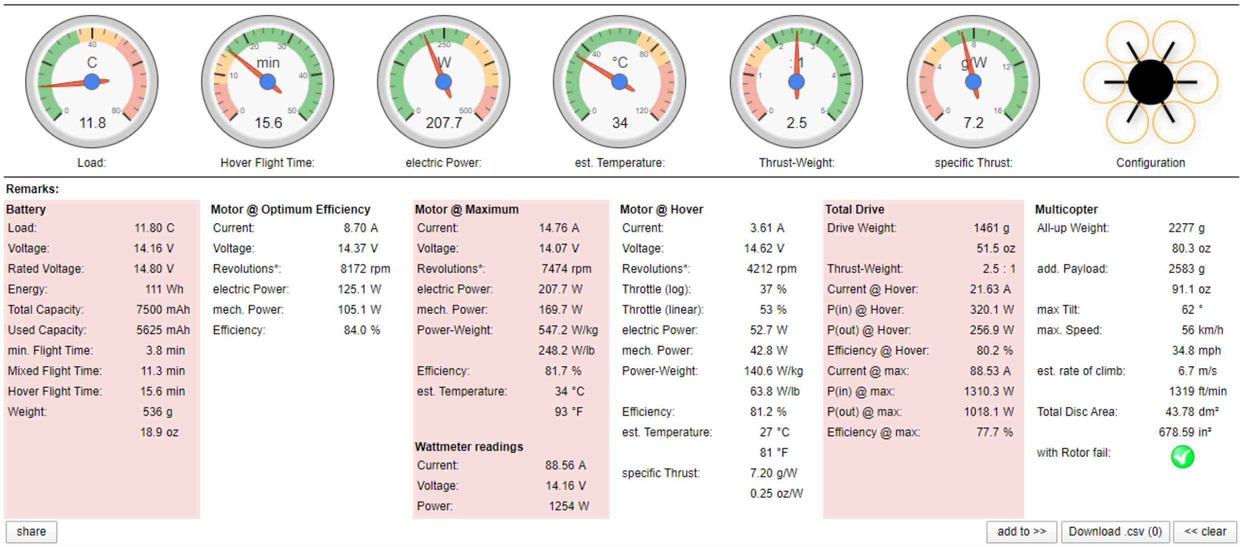


Figure 8: Flight Time analysis

The hover flight time, the best case scenario of total flight time, is 15.7 Minutes. This met our engineering specification number of 15 minutes.

The Flight time and flight range graph is shown below. The range with drag included is shown to be only 1.6 miles at 12 MPH for 9 minutes of flight time. This is less than we expected, but from our field trials with the drone flying, it appears that the flight range could increase, and this model is inaccurate. But without the ability to do flights in warmer weather for longer durations, it will be hard to know the true impact of the weight of the sensor load on the drone. In conclusion, the drone with its added payload barely makes it over the engineering specs, but the analysis might be flawed.

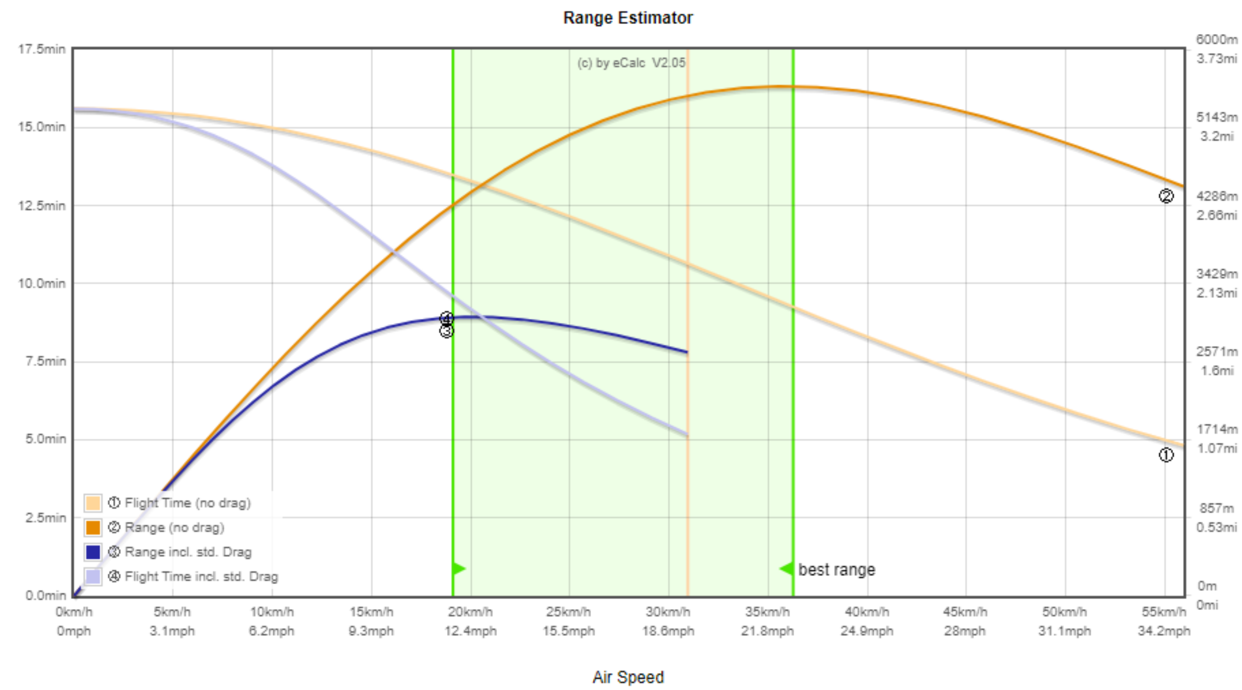


Figure 9: Flight time and range

CFD Simulation of forces acting on Sensor holder in air at maximum flight velocity

A Computation Fluid Dynamic simulation using Ansys Fluent was used to compute the forces acting upon the hanging wire and Sensor mount when the drone is flying at maximum velocity. This is important as the maximum force the sensor wire can hold without detaching using its safety detachment is 6.6 Newtons currently. The wire detachment system was included for safety if the drone ever got the sensors and/or wire caught in an object, and couldn't free itself, thus losing the drone at that location, possibly in the middle of Lake Champlain. The fear of having the safety detachment force being low is that some force might detach it when it is not in need of a safe escape. One such example is flying around with the wire and sensor holder at maximum velocity in the air. This simulation was to see if in this situation, would the wire and sensor holder detach.

The CFD simulation below represents a 2D cross-section of the wire and sensor holder being affected by a velocity created by the propellers. The sensors are modeled to be 4 meters below the drone, the current length of the wire. The velocity of the propeller wake was calculated based on the top speed of the drone, 38.4MPH. This of course is assuming the worst forces created by the drone on the sensor holder, and the air velocity would never realistically reach such a high number. Rather, speeds of 60% of the maximum would be expected in autonomous flight, or 24 MPH. The wire is modeled on the left side of the frame, and the small notch at the bottom represents the sensor holder's dimensions. As seen in the figure below, the large buildup of pressure on the top of the sensor holder is the main source of the resulting force on the sensor holder.

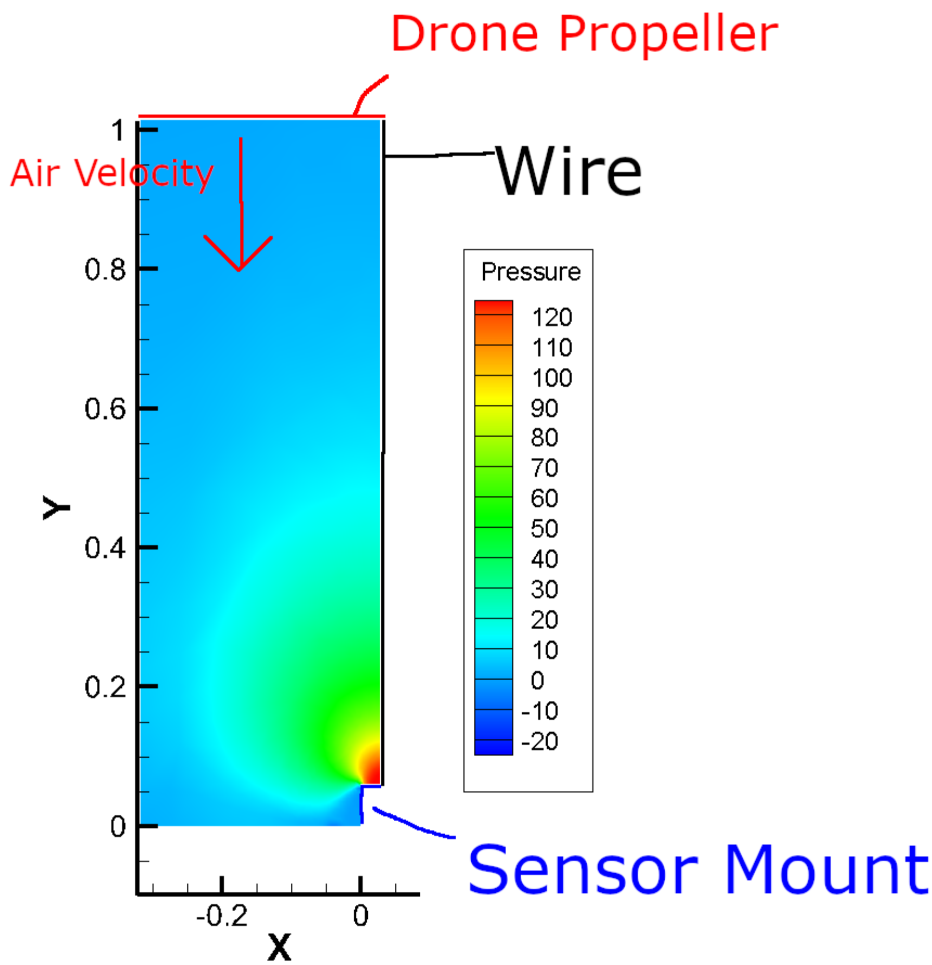


Figure 10: CFD simulation on sensor holder

The results of the forces on the sensor mounts are shown in table 1:

	Force (N)	Force (Lb)
Sensor Board Vertical Force	-3.465	-0.779
Sensor Board Horizontal Force	-0.245	-0.055
Wire Safety release limit	6.6	1.49

Table 1: CFD simulation results

The forces in the horizontal direction are minute, and less relevant as these forces would be canceled out due to the symmetrical nature of the propellers around the wire sensor holder. In the Vertical direction, the flat top and sharp edges of the sensor holder are what causes a large pressure build-up to occur, and thus the larger force exerted on the sensor holder. The vertical force on the sensor holder, and thus the sensor wire, is still half that of the wire safety release limit. As this force of 3.465N is created at the maximum speed for the drone, one can expect the force from the drone flying in normal conditions is far less than the safety release limit. In conclusion, there should be no worry of aerodynamic forces detaching the sensor system accidentally from the drone.

Sensor Response Time

The number of locations for water quality sensing is determined by the overall UAV flying ability and speed of data collection at each site. Our team has picked sensors (turbidity, temperature, TDS) that have a response time of less than 10s to optimize the number of data points collected. This analysis is directly impacting the engineering specification ID 20 (Sensor will allow the drone to fly for 15 mins) and ID 70 (the product shall produce color map for 5 different locations in 10 mins).

The analysis below (Figure 11) is based on the test of different sensors submerging from the standard atmosphere condition into liquid with pre measured parameters (1798NTU for turbidity, 32C degrees for temperature, 620ppm for TDS). The results were collected using the Arduino IDE monitor and imported into Matlab to create the following figure. The thresholds were plotted based on the engineering specification ID 80. All three sensors have shown a settling time within the given threshold of less than 10s. This analysis was based purely on the datasheet of the sensors in the old document and now supported by the tested data set with high confidence.

Assumptions made in this analysis:

- The pre-measured parameters of the liquid do not change for more than 20% (The biggest threshold for all three parameters is 10%) over the course of measurement.
- The arduino sampling time was set to 1s per sample, so it is assumed the values of the liquid does not change faster than 1s of time.
- The condition of the known liquid is different from the Champlain Lake water, so it is assumed that the sensors will be used in the linear region of the response curve.

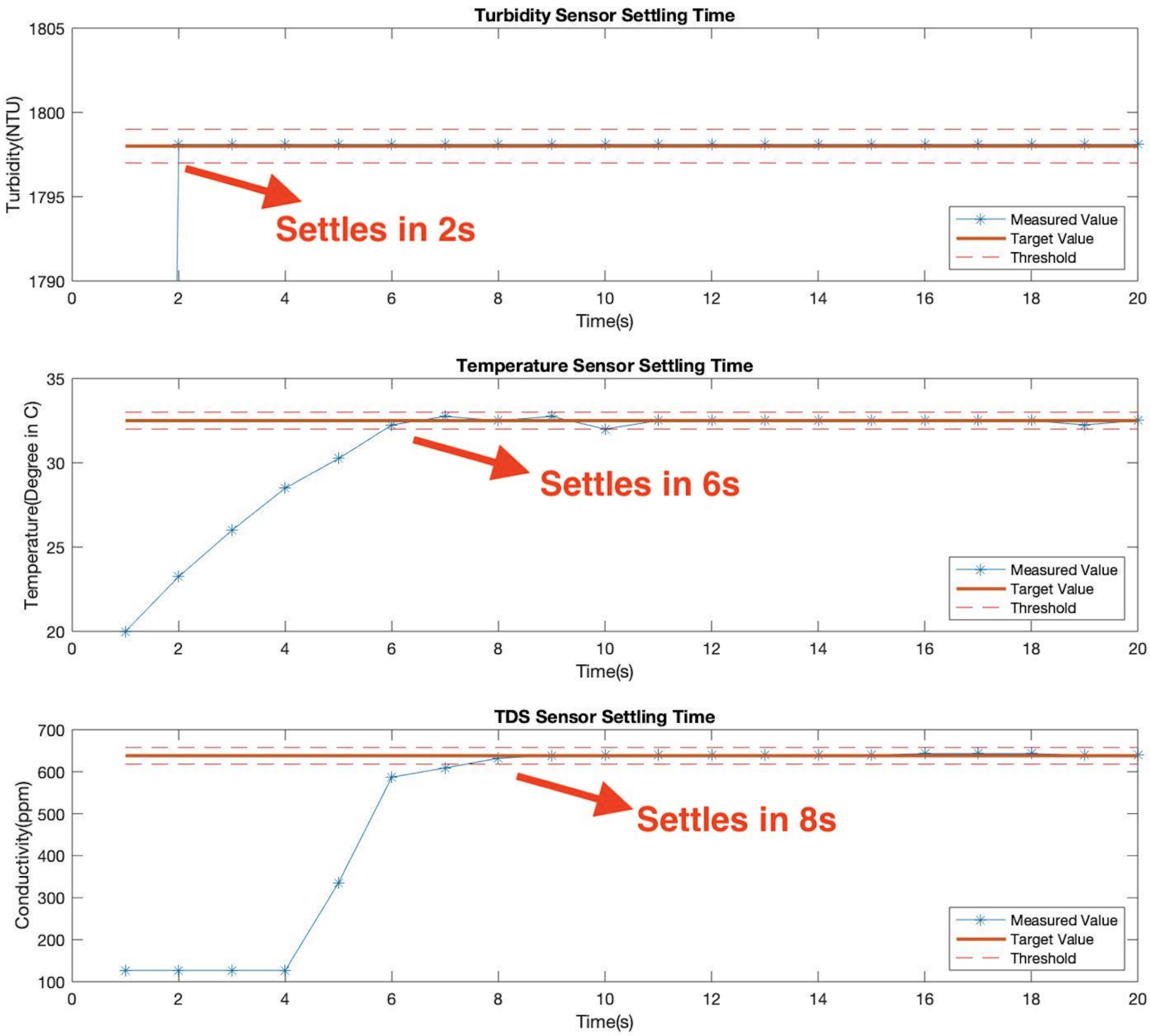


Figure 11: Sensor response time analysis plot

Power Analysis

The major power consumption in the system comes from the electronics in the sensor box. Two critical concerns in this analysis are to make sure the individual modules do not exceed the Arduino Mega current capacity and the sensor system has enough power to operate for the duration of the water sampling mission. This analysis directly relates to the engineering specification ID 20 (THe sensor will allow the drone to fly for 15 minutes) and ID 70 (The product shall produce color map from data collected in 5 different testing spots in less than 10 minutes).

The voltage, max current, min current for each electrical component and module were extracted from the datasheet (Table 2). For the components missing any of those parameters from the datasheet the following assumptions were made:

- A max current of 40mA for each pin was assumed since it is the max DC current for one Arduino Mega I/O pin.As most of the modules are built to be working with Arduino, the above assumption is reasonable.
- A min current of 20 mA for each pin was assumed. The min current for modules were assumed to be only when power in and ground pin were used. All the modules were connected directly to the arduino, so only when digital signals are sent to other pins, the additional pins will consume power. Based on the sensor settling time analysis, most of the modules will only be in use for 10s at each data location. At other times, the sensor system will consume extremely less power than the active mode.

The power was calculated by the equation (1).

$$P = IV \quad (1)$$

Component	Voltage(V)	Max Current(mA)	Min Current(mA)	Max Power(mW)	Min Power(mW)
MAX6675	5	240	40	1200	200
NEO-6M	5	160	40	800	200
SEN0244	5	6	3	30	15
SEN0189	5	40	20	200	100
ESP32	5	120	40	600	200
MicroSD	5	200	40	1000	200
2N3904	5	200	0	1000	0
R 22k	5	0.2	0.2	1	1
R 50k	5	11	34	55	170
R 50k	5	11	34	55	170
Arduino Mega	12	70	60	840	720
Sum (Mega Excluded)		988.2	251.2	4941	1256

Table 2: Voltage, current and power consumption of each electrical components

A more realistic power estimation was made based on assumptions mentioned above. The ratio that sensors are in active mode and in sleep mode is estimated to be 50s : 10x60s = 0.08. This ratio reflects the ratio of time sensors use in max power and min power. So the average power consumption is calculated by equation (2) to be 1.54W.

$$P_{ave} = 0.078 * P_{max} + 0.922 * P_{min} \quad (2)$$

With the LiPo 11.1V 1300mAh battery and 251.2mA of drain rate, the usage time can be calculated by equation (3) to be 248.6 minutes.

$$T = Battery\ Capacity \times Battery\ Discharge \div Amp\ Draw \times 60 \quad (3)$$

Where battery discharge for LiPo batteries are 80%.

Given an 11.1V input to the arduino Mega, the linear regulator of arduino mega SPX1117M3-L-5-0/TR converts the voltage to 5V and supplies it to the other components. The max current output of this linear regulator is rated at 800mA which is 23.5% lower than the estimated sum max current. So in cases that all the components reach their maximum rated current and all active at the same time, the circuit poses risk of overloading. However, based on the datasheet, most of the electrical modules have a typical operating current very close to the minimum current. Thus, if additional components are added to the circuit, power analysis is strongly recommended.

With the current design, the sensor system has sufficient usage time for multiple missions of water sampling and operates normally under the Arduino Mega current rating.

Transmission Range

As mentioned above, the data collected by the Drone must be sent to the Gateway using a LoRa end-node. The LoRa end-node, as other transmission systems, has a transmission range if the Drone during sampling ends up being outside that range the data transmitted will not be received by the Gateway which will cause data loss. This analysis will determine if the LoRa transmission system range is large enough to convert the fly range of the Drone. The analysis is related to the specification ID 50: The transmission system shall be able to transmit data within 3 miles of range.

The 3 mile range is used in this analysis for the purpose of the worst case analysis otherwise it is greater than the fly range of the Drone. It is reasonably a difficult range to be violated by the Drone for the following reasons:

- The Drone (without the sensors system) has a fly time of 15mn
- The Drone must fly more than 6 mile round trip in 15mn while sampling to be outside this range
- The Drone operator by “law” must be able to seen the Drone while it is flying
- It is also greater than the remote control range

This is a new analysis, it has not been performed in the Fall semester.

The analysis will use a tool used in communication called Link Budget. “A Link budget is an accounting of all of the power gains and losses that a communication signal experiences in the telecommunication system; from a transmitter, through a medium (free space, cable, waveguide, fiber, etc.) to the receiver.” [9] Information from the configuration of the mDot-915 (the LoRa Module) and the Gain of the antenna used in the design will be used to calculate the power of the signal sent by the transmitter. The Link Budget technique will determine the power of the signal at the receiver module (another mDot-915). The mDot-915 has a Maximum Receive Sensitivity which is the minimum power the transmitted signal must have at the receiver end so that the receiver module can convert it back to the transmitted data. Therefore, after the Link Budget, if the power of the received signal is greater than the Maximum Receive Sensitivity, it can be concluded that the LoRa is able to transmit data 3 miles away from the Gateway.

To ease calculations, the signals power are converted to dB or dBm (decibel with reference to 1 milliwatt) and the Gain of the antennas in dBi (decibel over Isotropic). Using dB throughout the analysis will turn the multiplications and divisions into additions and subtractions, greatly simplifying calculations.

A complete link budget for an obstructed line-of-sight link will at least include the following factors:

Signal of the factors	Description of the factors that contribute to the Link Budget
+	Transmitter module output power
-	**Attenuation in the transmitter's antenna cabling, including any impedance matching network**
+	Transmitter antenna gain in the direction of the receiver
-	Propagation loss in free space

-	**Attenuation due to absorption in atmospheric gases**
-	**Margin for attenuation due to rain**
-	**Margin for attenuation in tree foliage**
-	**Margin for attenuation due to reflection against walls etc.**
	Margin for signal fading
+	Receiver antenna gain in the direction of the transmitter
+	**Attenuation in the receiver's antenna cabling, including any impedance matching network**
=	Signal strength at the receiver input terminals, to be compared with the minimum necessary signal strength

Table 3: Summary of the factors needed in an obstructed line-of-sight link budget

Assumptions:

- The analysis is considering only the simple case of unobstructed line-of-sight since the test of the specification ID 50 will be performed with the LoRa end having a direct line-of-sight with the Gateway
- The transmitter and receiver antennas will be considered perfect
- The Drone will not operate under the rain
- The 3 miles range is short to neglect the signal fading, and the effect of the atmosphere gases. In 3 miles, the attenuation of the two compounds responsible for the majority of signal absorption: oxygen (O2) and water vapor (H2O) at the frequency of 915Mhz is about 0.0126dBm.

Based on those assumptions, the effect of the factors bolded in the Table above will be neglected in the Link Budget.

Contribution of the different factors into the link budget:

- Transmitter module output power: **11dBm**. The mDot-915 module still has the default Transmit Power setting. The Transmit Power can be changed by the command AT+TXP=<Value>, with <Value> been between 2-20dBm.
- The Gain of the Transmitter and Receiver antennas: **5dBi** which is equal to **35dBm**. To convert dB or dBi to dBm just add 30 to the dB or dBi value.
- Propagation loss in free space:

$$20 \times log_{10}(4 \times \pi \times \frac{d \times f}{c}) \tag{4}$$

Where d = 3 mile = 4.828km (the range), f = 915Mhz(the frequency of operation),

and c=300*10^6km/s (speed of light).
Power loss in free space = **105.346dB = 135.346dBm.**

The unobstructed line-of-sight Link Budget can be summarized as followed:

Contribution in dBm	The factors
+ 11	Transmitter module output power
+35	Transmitter antenna gain in the direction of the receiver
-135.346	Propagation loss in free space
-0.0126	Attenuation due to absorption in atmospheric gases
+35	Receiver antenna gain in the direction of the transmitter
= - 54.359	**Signal strength at the receiver input terminals, to be compared with the minimum necessary signal strength**

Table 4: Summary of the unobstructed line-of-sight link budget.

The signal strength at the receiver is approximated to **-54.359dBm** by the link budget, and from the datasheet of the mDot (Figure# below), the minimum usable signal at the receiver (Max Receive Sensitivity) is **-130 dBm**, this gives a huge margin of about **75.64dBm**.

Admittedly, the above link budget shows that the transmission module as received from the client, that is the configuration of the mDot-915 and the antenna provided by the client, can send data at least 3 mile away from the Gateway. One should keep in mind this is only in the particular case where the LoRa end-node has a direct line-of-sight with the receiver. Therefore, in practice the power margin of 75.64dBm obtained above could easily be absorbed by the factors such trees, landscape, interference from other signals, and buildings which may cause data loss. Theoretically, for this project, the transmission should work normally since the lake Champlain provides an open landscape with less obstructions to a Gateway located at Rubenstein building.

To better deal with interferences, the power margin can even be improved by:

- Using omnidirectional antennas with higher Gain, 15dBi for example
- And also increasing the transmitter module power from 11dBm to 20dBm but this will also increase the power consumption by 14mA (See datasheet excerpt below)

SPECIFICATIONS

Models	MTDOT-868	MTDOT-915	MTDOT-923
Region/Country	Europe	North America / Australia	Asia Pacific
Power			
Max Transmitter Power Output (TPO)	14 dBm	19 dBm	Varies by Country
Max Receive Sensitivity	-137 dBm	-130 dBm	Varies by Country

Figure 12: mDot datasheet: the Max Receive Sensitivity of mDot 915-Mhz is -130dBm

POWER DRAW

Voltage	3.3V		5.0V	
Sleep Mode (Version 0.1.2 or newer)	40.0μA			
Idle Current Average (Amps)	0.032			
Packet Size (Bytes)	10	53	19	53
Average Current (Amps) at Low Transmit Power Setting (TXP 2)	0.026			0.025
Average Current (Amps) at Default Transmit Power Setting (TXP 11)	0.028	0.029	0.028	
Average Current (Amps) at Maximum Transmit Power Setting (TXP 20)	0.031	0.041	0.032	0.042
Total Inrush Charge Measured in Millicoulombs (mC)	1.14		1.79	
Total Inrush Charge Duration during Powerup (InRush Duration)	661μS		1.24mS	

Figure 13: mDot datasheet: With 5V power supply and 53 bytes package size, the mDot need 24mA to send a signal of 20dBm (TXP20)

The LoRa Data Transmission Rate

In this project, the LoRa will be operating with a bandwidth of 125Khz. With that bandwidth, the LoRa end-node (LoRa on the drone) will be able to send **0.3kbps to 27kbps** of data. Since the bandwidth is fixed, the data transmission rate is affected by the distance of the LoRa end-node to the Gateway and interferences (buildings, trees, landscapes, etc...) between the Drone and the Gateway. This analysis will determine if with the worst data transmission rate (0.3kbps) the LoRa could send data from a sampling before the next sampling data is available to the module. If data from a sampling is written to the LoRa serial while it is still sending data from the previous sampling that could cause a data loss. The analysis is related to the specification ID 60,"The transmission system shall transmit collected data with less than 2 mn delay." and the specification ID 100, "The LoRa end-node shall be able to send at least 300 bps of data."
This is an old analysis but the following things have changed:

- The PH sensor has been removed from the design
- The GPS is not longer using the UTM Coordinate system

- The Team has learned during a test that the LoRa is sending with every data transmission an extra 13 bytes of information. Those 13 bytes represent the device ID, they allow the Gateway to differentiate data sent by this project from data sent by other LoRa end-nodes.

The analysis will be performed as followed:

- The LoRa can only send strings therefore every characters sent weight 1 byte (Ascii code)
- The weight of the data to be sent will be determined
- The total weight of the information to be sent will be calculated by adding the weight of the device ID to the weight of the data.
- Calculate the time the LoRa needs to send the total information in the 300bps data rate (worst case).
- Determine how this result and results from other analyses will affect the design.

The data that will be collected and sent from the drone to Gateway are the GPS coordinates, Temperature, Turbidity. And each of those parameters will contribute to the weight of the data as followed:

- GPS Coordinate:
  Example: 44.478489,-73.199033 (the coordinate of Williams Hall at UVM)
  The GPS needs **20 bytes** since each character takes 1 byte
- Turbidity:
  Example: 1554.34
  It will take **7 bytes** to send the Turbidity data.
- Temperature:
  Example: 32.750
  It will take **6 bytes** to send the Temperature data.
- Number of Commas or Spaces:
  Two commas or spaces will be used to separate data from the GPS, Turbidity, and Temperature sensors. Therefore, **2 bytes** will be added to the weight of the data due to those commas or spaces.
- Total bytes needed for the data to be sent:
  20 bytes + 7 bytes + 6 bytes + 2 bytes = **35 bytes**
- Total weight of the information sends by the LoRa after every sampling:
  35 bytes + 13 bytes (weight of the device ID) = **48 bytes**
- Conversion of the total weight from byte to bit:
  48 bytes * 8 bits/byte = **384 bits**
  A total of 384 bits of information will be sent by the LoRa end-node after each sampling.

In the worst case, meaning when the LoRa is transmitting 300bps of data , it will take the transmitter **1.28 second** to send all the data from one sampling. According to this analysis, the minimum time two consecutive sampling shall be greater than 1.24 second to prevent a data loss. However, the team knows that this minimum time needed to transmit all the data will increase if extra sensors are added to the system or if the accurry the measurements are increased. It (the team) also knows that in practice the loRa could transmit less than 300bps which will also increase that minimum time.

From the analysis “Sensors Response Time”, the maximum settling time of the sensors was 8 second. Meaning that a pause of at least 8 second must be added to the Arduino sampling code to allow all the sensors to settle before collecting the data. In that case, the sampling code will not allow two samplings in less than 8 second interval therefore only data transmission rate less than **48bps** (348bit/8second) will cause data loss. This design has a robust transmission rate; the worst data transmission rate could be lower to **48bps**, that is any worst transmission rate between **48bps to 300bps** will not cause a data loss.

Engineering Specification

Summary of the results that met the design specifications:

- The weight of the sensor system was measured to be 515.4 g which was below the maximum load of 2 kg allowed by the specification ID 10, The sensor payload shall be at maximum 2kg.
- According to the telemetry logs, the battery provided a fly time of 17 mn. That fly time was 2 mn higher than the 15 mn fly time required by the specification ID 20, The sensor payload will allow the drone to fly for 15 minutes.
- The whole sensor and communication systems cost $289.87. The money spent on those parts was within the budget of $500 imposed by the specification ID 30, Sensors system shall cost less than $500.
- The team spent $120 on the sensors and the sensor wire. The money used for this part of the design was less than the budget planned by the specification 40, The sensors and sensor wire (detachable parts) shall cost less than $300.
- The current design is equipped with a Turbidity, a Temperature, and a conductivity sensor. The accuracy and the settling time of each sensor was tested and was found to be in the tolerance range indicated by the specification ID 80,The product shall equip turbidity, temperature, and conductivity sensors with a minimum accuracy of 1NTU, 0.5Deg Celsius, and 20ppm respectively and with settling time less than 10s .
- The dimension of the sensor box is 27.9 cm x 20.3 cm x 14 cm. This dimension satisfies the dimension in the specification ID 90, The sensor box shall be less than 50cm x 50cm x 50 cm.
- An average force of 6.6483 N was needed to release the detachable cable from the sensor board. This test results is related to the specification ID 20, Sensor cable shall release at a force greater than 20N.

- Specification ID 130, The product shall equip a camera that takes at least 3 of the 2K pictures in synchronization with the triggering sensors and also produce analog video.

Specifications that did not Pass:

- Specification ID 50 , The transmission system shall be able to transmit data within 3 miles of range
- Specification ID 60, The transmission system shall transmit collected data with less than 2 mins delay.
- Specification ID 100, The LoRa end-node shall be able to send at least 300bps of data.
  The test for specification ID 50, 60, 100 had failed before (Fall semester) due to the interferences (trees and building) between the LoRa end-node and the gateway. In these new tests, the data was sent from the fifth floor of Williams Hall Building (at UVM) to reduce the interferences by providing a relative direct line of sight between the LoRa and the Gateway of IoT conduit. But the tests still failed due to the Bandwidth limitation on TTN and on the internet caused by the COVID-19 situation.
- Specification ID 110, The GPS data shall be accurate to within less than 5 meters.
  This test failed because the Continuously Operating Reference Station (CORS), a point with a well known GPS coordinate, was closed to a building which caused interference with the GPS module used in the test. Only an accuracy of 10 meter was measured from that CORS.

Specification that have not been tested:

- Specification ID 70, The product shall produce color map data from 5 different testing spots in less than 10 minutes.
  This specification has not been tested because at the time of the tests being performed the team did not know how GPS coordinate and sensor data can be represented on a map.

ID	Relative Weight	Engineering Specification (Threshold Value)	Stretch Value	Units	Notes	Verification Method	Verification Result	Verifiation Status (Pass/Fail/Not Tested)	Notes
10	12%	The sensor payload shall be at maximum 2kg	0.75	kg	Changed the object to sensor rathan than drone	Test	0.515 kg	Pass	
20	9%	The sensor payload will allow the drone to fly for 15 minutes	30	Minutes	Changed the object to sensor rathan than drone	Test	17 Minutes	Pass	
30	6%	Sensors system shall cost less than $500	300	USD	Not finalized but expected value is less than $300	Inspection	$290	Pass	Current iteration of materials, without
40	10%	The sensors and sensor wire (detachable parts) shall cost less than $300	200	USD		Inspection	$120	Pass	Does not include labor to construct, but materials
50	6%	The transmission system shall be able to transmit data within 3 miles of range	4	Miles	Technically the Drone does not have enough Battery power to fly a 6 miles, a round trip. But beeing able to transmit data 3 miles away from the Gateway will be a good indicator that the transmitted siganl has enough power to overcome some of the interferences that could cause data loss.	Test	0.5 mile	Fail	The transmission is tested within a 0.5 mile distance. Further, the transmission testing is limited by the physical building block in the Burlington area.
60	4%	The transmission system shall transmit collected data with less than 2 mn delay.	1	Minutes	The data is transmitted into the TTN cloud, so accessing the data might have delay time.	Test	less than 5s within 0.5 mile	Pass	The data transmission was successful and can be acquired at the node red platform from a Respberry Pi
70	5%	The product shall produce color map from data collected in 5 different testing spots in less than 10 minutes.	10	n/a	The collected data will be represented by dots on a map where the shade of the dots will correspond to a range of values.	Simulation		Not Tested	Will have to wait till drone is finished and flying to test the
80	10%	The product shall equip turbidity, temperature, and conductivity sensors with a minimum accuracy of 1NTU, 0.5Deg Celsius, and 20ppm respectively and with settling time less than 10s .	4	NTU, Deg Celsius, ppm, and Second.	Added accuracy and settling time requirement	Inspection	Temperature sensor and turbidity sensor all meet the requirements, but can not sychronize the camera with the rest of the system and still waiting for the water conductivity sensor.	Pass	
90	6%	The sensor box shall be less than 50 cm x 50 cm x 50 cm	20	centimeter cube	Changed the object to sensor rathan than drone	Inspection		Pass	
100	3%	The LoRa end-node shall be able to send at least 300bps of data.	1000bps	bps	The minimum data collected per sampling is about 312 bits. The LoRa must be able to send amount data before the next sampling.	Test	150 bytes per package	Fail	After talking with IoT engineer, it is not recommended to send data every second through TTN. However, our test has shown sufficient transmission speed for all the data we need to transmit.
110	12%	The GPS data shall be accurate to within less than 5 meters	4	meters	Changed requirement to GPS from drone failsafe feature'	Test	10 meters	Fail	Tested with our GPS module, the results showed 10 meters accuracy
120	10%	Sensor cable shall release at a force greater than 20N	10	Newton	This requirement was added after consulting the customer. The sensor cable will have a detachable segment where it is connected to the sensor box	Test	6.6N	Pass	Might change the Engineering specification to have a low limit of 10 N
130	9%	The product shall equip cameras that takes at least 3 2K pictures in synchronization with the triggering sensors and also produce analog video	2	count	Added when clients requested images of water to be added	Test		Pass	

Figure 14: Engineering specification Screen Shot

Impact Statement

The product was built in compliance with the NSPE code of Ethics for engineers. In conjunction with the NSPE fundamental canons ``hold paramount the safety, health, and welfare of the public”, the team has strictly followed the UAV operation guidelines by UVM UAS working group, and FAA. More specifically, under the safety and ethical concern, the team has always operated the drone at locations more than 5 miles away from the Burlington airport. Pre-flight checking also includes clearing the area of 50m x 50m for the safety of the public. As UVM students, team members could have saved more time by testing drones on the empty grounds on campus. However, the team had made the decision to act ethically and safely.

Additionally, the testing of the drone on the water has posed the risk of the drone falling into the water. The major cause of this result as concluded from FMEA is that the sensor wire caught by objects on the lake or plants and animals under the water. In order to mitigate this risk, the team has designed a releasable sensor wire so that only certain force is allowed to drag the wire before it releases. The released sensor wire will become a waste that goes into the lake champlain, which becomes an ethical issue for the product. However, this design decision was made to also make sure the safety of the unknown object. The team has reasoned that the crashing of the whole drone will cause more damage to either the unknown object or the lake. So the ethical sacrifice was made to leave the sensor wire behind in order to minimize the impact on the public and environment at the same time as to increase the safety of the product.

The team also followed ethical guidelines by having team members only perform duties they felt comfortable doing and had experience with. The NSPE Code of Ethics states “Engineers shall perform services only in the areas of their competence.” A perfect example of the team following this guideline is when piloting the drone. Nathaniel is the most familiar with piloting drones and was certified to fly prior to the start of the project. Because of his qualifications, Nathaniel was the primary pilot and he was able to safely operate the drone during test flights.

Lessons Learned

Looking for Expert Resources for Help:

When engineers like our team start to work on a project, a good way to get more understanding on a topic is to reach out to local experts. This strategy has benefited the team throughout the year. For example, at first the team found out that the accuracy of the existing GPS is not enough for the requirement. However, the team didn’t buy a 200 dollars GPS module suggested by the client because the team consulted the GPS experts at UVM. Their experience helped the team understand how to operate the GPS more effectively and saved the team budget. The team also reached out to the UVM high frequency lab for PCB design and production. The experts there helped the team revise the PCB design, performed a couple test production before the team was ready to fabricate the final version of PCB. The team would have spent more time learning about the PCB design and made small mistakes on the schematics, which would have delayed the project progress for a couple months if the team had not reached out to the local experts.

Alternative Design Choices

The transmission system was partially offered by the client. The team's job was to test and further implement the transmission system into the final product. The team has researched other options for the transmission but they would require new hardware and more time. So the team only focused on the Lora transmission system through the Things of Network platform for transmission. During the pandemic period, the Europe server shut down which directly limited the bandwidth the US had for the transmission channel. Because of this, the previously tested successful requirement failed. Had the team kept a backup plan for the transmission system, there was a chance that the project completion rate would be a bit higher. The team has concluded that the pandemic was a very low chance event, but always having alternative design choices in the back pocket is a good lesson learned.

Team Communication and Dependencies

The electrical system and mechanical system are tightly connected in this project. One of the biggest lessons learned is that team members should always communicate with each other while making decisions. For example, the use of Arduino Uno was first determined by the electrical side of the team and communicated to the mechanical side of the team. So the first revision of the sensor box was designed for Arduino Uno. However, in Late November, the electrical side of the team switched to Arduino Mega but didn't inform the mechanical side of the team. So the second revision of the sensor box was a failure since things don't fit in. This wasted the team 2 weeks of redesigning and 3D printing for the sensor box.

Buy Spare Parts

The team has learned that buying spare parts would save time and money when critical parts in the system fail from the SEED lecture. However, due to the budget limitation, the team only bought the critical spare parts (motors, propellers, drone arms, electrical components) for the project but not every individual part. This still resulted in the team a 2 weeks of delay in drone fixing after the drone crashed to the ground and broke the supporting legs. The team should have analyzed the high risk part of the drone and also purchased spare parts for those risky portions. Waiting for the parts to arrive not only delays the working progress of the team, but also leads to unexpected longer delay for the whole project during the intervention of pandemic.

Conclusion

Successes realized in the project:

- Test flights of the drone were promising. The drone was stable with the added payload and capable of prolonged hover (longer than 10s) for sampling data recovery
- Most of the design requirements and specifications were met
- The expenses were within the limit of the budget
- The transmission system is working . Short distance test performed between Votey and the students' dorm (on campus) has shown that data being transmitted successfully to the Gateway located at Votey..
- Sensors and the GSP module successfully collected data along with location information
- System is modular, with ability to connect up to 5 sensors and mount to different drones.

Differences between the current design and the original Project Scope Statement:

- SD card writer and reader is added to the design
- Camera and ultrasonic sensor are added to the design
- PH sensor will not be used in the design
- The drone is no more autonomous
- A working prototype will not be provided to the clients
- An operation manual will not be provided to the clients

How does the design solve the problem?

- The Blue-Green Algae is known to trieve in a temperature range of 20C to 30C
- Its presence in the water increases the turbidity of the water
- Its presence will also change the color of the water
- This design will use the Temperature, the Turbidity, and the Picture of the water to indirectly determine the presence of the Blue-Green Algae in the water. It is also a very cheap alternative since a good algae sensor can cost around $3200 (YSI 6210 Total Algae PC Sensor for instance)

The future tasks to perform if the team had to keep working on the project:

- Test the transmission system
- Waterproofing of sensor box and electronic components

- Reduce size of and materials used in sensor box
- Improve design of sensor holder
- Design a more reliable transmission system by providing, for instance, a bi-directional communication between the LoRa and the Gateway. And a better cloud must be used to store the collected data.
- Upgrade the device so it can sample at different depth of water

Appendix

Project Retrospective

The most impactful Kaizen has been to "write down everything, and for digital information, take screenshots of everything. Nothing is too small not to record". Writing things down and documenting consistently is important because it allows the team to track progress as well as the client. For example, early on in the project the initial ideas for how the sensor mount would look started off as simple sketches. The drawings were saved and put into google docs. These rough sketches later on became the basis for our final design. This small change has also made it easier to perform as a team while separated due to the Pandemic. It was necessary for the Team to start measuring our progress differently during these unusual times because we were unable to all meet in one place and physically work on our project. The team was very successful in remaining positive and continuing to put in effort.

The team's velocity was high at the beginning of the semester and increased for the first month of classes. The team members were all fresh from break and eager to contribute to the project. The velocity began to slow as team members began to focus on other classes for midterms and as spring break approached. The majority of the drone assembly was done approximately a month into the semester. Work continued to be done and then dropped off a week before spring break. Obviously, the pandemic has had a severe effect on the team's ability to work, however after an initial lull in progress, the team continued working hard on deliverables and

computer simulations and designs. The three team members in Burlington were even able to test the drone with the appropriate social distancing measures put in place.
The team's happiness followed a few interesting trends. Happiness with the team continued to rise for the first 4 sprints as team members grew closer and then flattened at almost a 5. The sprint happiness was stable until the 5th sprint when it dropped off. This coincides with the onset of the Covid 19 Pandemic. The decline in happiness had to do with decreased productivity and the move to digital formatting. Happiness with the course remained the most stable. The lowest dip in course happiness occurred during sprint 3 which was due to the stress of course presentations as well as finals in other classes.

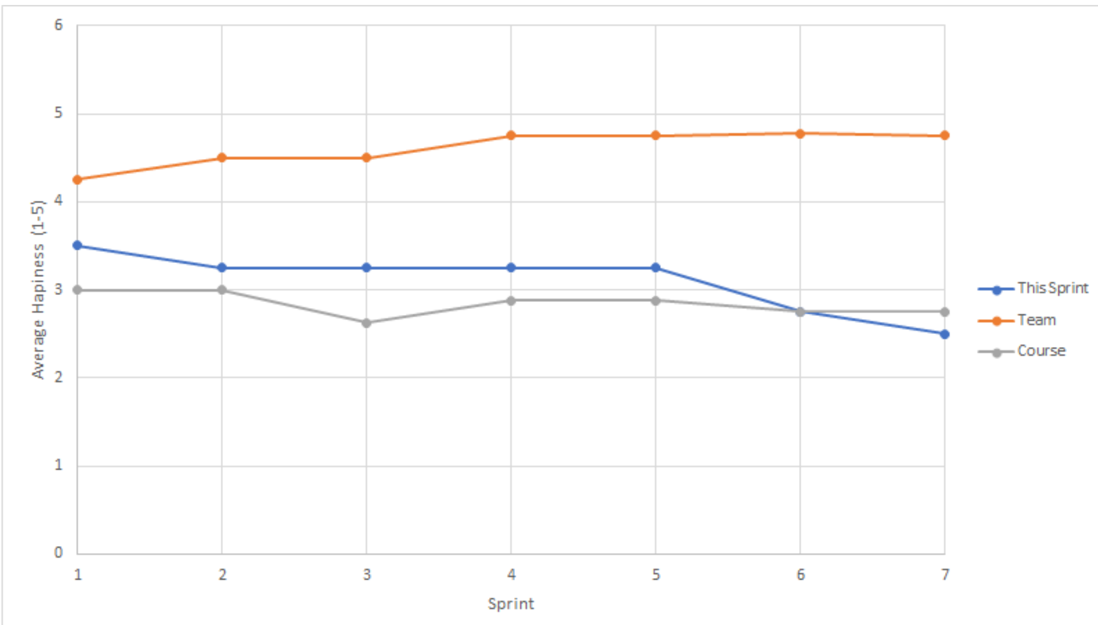


Figure 15:Team Happiness Chart

Product Retrospective

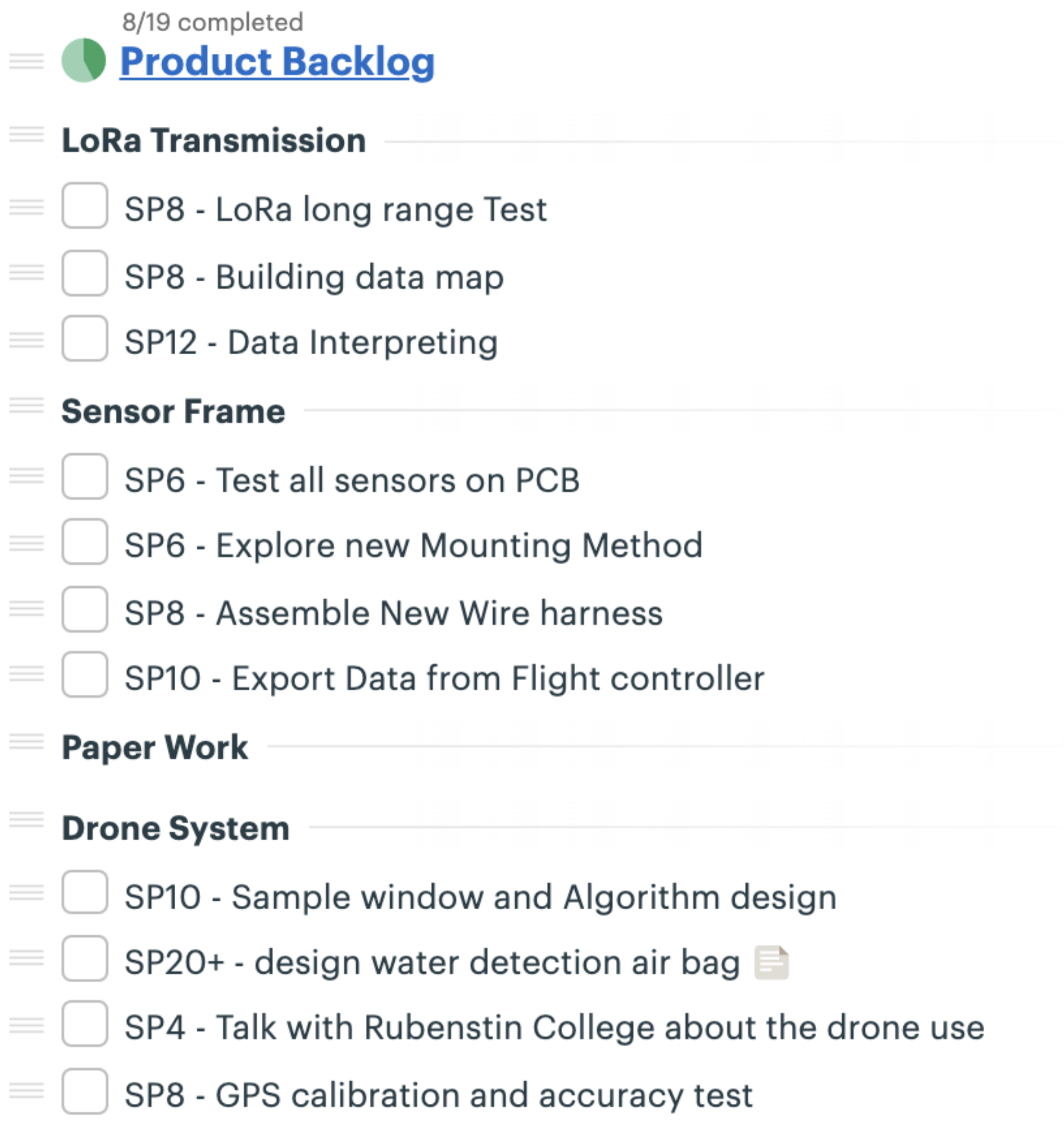
The client and team members were happy with the overall sprint product for the following reasons:

- Each sprint has a relatively accurate story point estimation corresponding to the actual task. Thus, the team member was able to pick up the tasks effectively and the whole team achieved an average of 65 story points each sprint.
- Under the scrum and sprint methodologies guidance, the team was able to present the product backlog, tasks done, and retrospective to the client to discuss the potential

backlog to put into the following week. The continuous progress making each week makes the client feel productive about the team

- Each sprint captures the good and bad events that happened to the team. The client has a better understanding about the status of the students so that they didn't come up with unrealistic goals for students.

The product backlog is presented below:



The remaining backlog that's essential to the project success:

- LoRa long range Test: Due to the pandemic intervention, the bandwidth of the TTN cloud was limited. The LoRa mid range test was performed by the team and failed the requirement. This requirement plays an essential role in the performance of the product in the way that it limits how far the drone can fly to collect data. So, when the bandwidth recovers, this long range test shall be done.

- Test all sensors on PCB: the PCB for the project was designed and printed in the high frequency lab for testing for 4 revisions. However, the final version of PCB was not printed due to the halting of the budget at the end of the semester. The sensor system theoretically should work well, but testing of the whole system would still be required before the product can fly to collect data.
- Sample Window and algorithm design: the team focused on the hardware and design on the project for the first semester and testing for the second semester. However, the software side of the project was expected to be done at the end after the team had field testing with real water samples. Obviously the team hasn't moved that far. But sampling algorithms are very important for avoiding unpredictable events, increasing data accuracy and storage efficiency.

Budget

Item	Cost
Arduino MEga	28.90
Xbee shield	16.95
Mtdot board	54.03
blue medium strength vibra-tite	1.38
black electrical tape	2.10
Frame Motors ESC PRops	349.00
Battery	87.98
FLight Controller	128.86
RC Transmitter	125.99
RC Transmitter Battery	22.58
RC Receiver	36.99
extra motor	36.99
extra propellers	32.26
extra esc	40.00
Misumi Din board	4.90

Wire	29.66
Misumi DIN plug	5.33
RunCam Hybrid	99.99
Micro SD card	11.99
Pixhawk to FRSky	12.90
NEw 8 core wire	18.93
Thermocouple	12.99
64gb sd cards for pi and arduino	23.98
ultrasonic sensor	44.95
Thermocouple	14.20
TDS Sensor	22.12
SD card reader	6.99
New esp32 camera	19.99
TDS sensor	13.03
Drone arm snaps	14.70
Foam prop guards	7.80
Screw driver	10.90
velcro straps	3.90
Battery pad	3.90
New Mini-Din	16.45
Wire connectors	9.99
Total	**1373.60**

With Comparison to Original Budget

Total	**1373.60**
Original Budget	**1500.00**
What we have left	**126.40**

The original budget was frankly low for this project, as technically $1000 was dedicated to a drone that would be used by future SEED groups. This left $500 for the rest of the equipment, from sensors to LoRa transmission to any other parts needed (like spares). Compared to other budgets, $500 is on the low, if not the lowest, end.

While no budget was presented at the Preliminary Design Review, the estimated cost of the drone was $700, with the actual price being $879. This is compared to the commercial version of the drone which would cost $1500, not including spare parts. The extra price from $700 to $879 is due to the choice of extra motors, batteries, other small parts, as well as an RC transmitter with a larger signal radius that stock to reach.

References

[1]Espressif.com, 2020. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32_datasheet_en.pdf. [Accessed: 01- May- 2020].

[2]F. Test, "How To Estimate the Flight Time of a Battery", Flite Test, 2020. [Online]. Available: https://www.flitetest.com/articles/how-to-estimate-the-flight-time-for-a-battery. [Accessed: 01- May- 2020].

[3]"Power supply arduino mega", Forum.arduino.cc, 2020. [Online]. Available: https://forum.arduino.cc/index.php?topic=457823.0. [Accessed: 01- May- 2020].

[4]Media.digikey.com, 2020. [Online]. Available: https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SEN0244_Web.pdf. [Accessed: 01- May- 2020].

[5]Media.digikey.com, 2020. [Online]. Available: https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SEN0189_Web.pdf. [Accessed: 01- May- 2020].

[6]Datasheets.maximintegrated.com, 2020. [Online]. Available: https://datasheets.maximintegrated.com/en/ds/MAX6675.pdf. [Accessed: 01- May- 2020].

[7]"Arduino GPS Modules: Which one to use? Guide and Comparisons", Seeedstudio.com, 2020. [Online]. Available: https://www.seeedstudio.com/blog/2019/11/06/arduino-gps-modules-which-one-to-use-guide-and-comparisons/. [Accessed: 01- May- 2020].

[8]A. Pandzic, D. Hodzic, and A. Milovanovic, “Effect of Infill Type and Density on Tensile Properties of PLA Material for FDM Process,” DAAAM Proceedings Proceedings of the 30th International DAAAM Symposium 2019, pp. 0545–0554, 2019.

[9]Thermoplastic,” Polylactic Acid (PLA, Polylactide) :: MakeItFrom.com, 20-Sep-2018. [Online]. Available: https://www.makeitfrom.com/material-properties/Polylactic-Acid-PLA-Polylactide/. [Accessed: 30-April-2020].[

[10]“Signal,” Wikipedia, 19-Apr-2020. [Online]. Available: https://en.wikipedia.org/wiki/Signal. [Accessed: 01-May-2020].

Prior Art References:

Feitian Zhang, O., Ennasr, Litchman, & Xiaobo Tan. “Autonomous Sampling of Water Columns Using Gliding Robotic Fish: Algorithms and Harmful-Algae-Sampling Experiments” *IEEE Systems Journal*, 10(3), 1271-1281.

J. Godoy, F. Cabrera, V. Arana, D. Sanchez, I. Alonso, and N. Molina, “A new Approach of V2X Communications for Long Range Applications in UAVs,” 2018 2nd URSI Atlantic Radio Science Meeting (AT-RASC), 2018.

J. Ore, S. Elbaum, A. Burgin and C. Detweiler, "Autonomous Aerial Water Sampling", *Journal of Field Robotics*, vol. 32, no. 8, pp. 1095-1113, 2015.

Lally, H., O'Connor, I., Jensen, O., & Graham, C. “Can drones be used to conduct water sampling in aquatic environments? A review.” Science of the Total Environment, 670, 569-575, 2019.
O. Khutsoane, B. Isong, and A. M. Abu-Mahfouz, “IoT devices and applications based on LoRa/LoRaWAN,” IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, 2017.

Y. E. Windarto, A. B. Prasetijo, and G. F. Damara, “A GIS-based Waste Water Monitoring System Using LoRa Technology,” 2018 5th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), 2018.

S. Park, S. Yun, H. Kim, R. Kwon, J. Ganser, and S. Anthony, “Forestry Monitoring System using LoRa and Drone,” Proceedings of the 8th International Conference on Web Intelligence, Mining and Semantics - WIMS 18, 2018.

Department of Defence, “Global Positioning System Standard Positioning Service Performance Standard,” US government, Washington D.C, USA, (4th edition), September 2008. Accessed: 2019 [Online]. Available: gps.gov/technical/ps/2008-SPS-performance-standard.pdf

M. Schwarzbach, M. Laiacker, M. Mulero-Pázmány and K. Kondak, "Remote water sampling using flying robots," 2014 International Conference on Unmanned Aircraft Systems (ICUAS), Orlando, FL, 2014, pp. 72-76.

G. Di Stefano, G. Romeo, A. Mazzini, A. Iarocci, S. Hadi, S. Pelphrey, “The Lusi drone: A multidisciplinary tool to access extreme environments,” Marine and Petroleum Geology, Volume 90, 2018, Pages 26-37,

Y. Shin, M. Gutierrez-Wing and J. Choi, "A field-deployable and handheld fluorometer for environmental water quality monitoring", Micro and Nano Systems Letters, vol. 6, no. 1, 2018. Available: 10.1186/s40486-018-0078-x.