Platform for Environmental Sensing of Algae

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Introduction

Background

An algal bloom is a rapid increase or accumulation in the population of algae in an aquatic system. Algal blooms create major problems for the environment and the economy. With global warming increasing the average temperature of the Earth and increased pollution in bodies of water, the possibility of algal blooms occurring go up as well. Algal blooms typically involve microscopic, single cell organisms, but can also extend to macroscopic, larger organisms such as seaweed.

Algal blooms normally occur due to a number of different factors which help provide the algae the optimal environment to grow. One major factor is when there are excess nutrients in the water. These excess nutrients can originate from the runoff and soil erosion from fertilized agricultural areas and lawns. The excess nutrients flow into rivers and accumulate at river mouths where it provides a high concentration of nutrients for the algae to thrive on. Algae typically grows when temperatures get warmer in the spring and summer months. The temperature increases provide optimal growth for the algae. Stagnant water or low turbulent water also encourage the growth of algae. Light is another factor that helps algae growth. Algae have optimal growth when intermittently exposed to high light intensities. These conditions are met under the surface of the water where light is fluctuating. [1]

Some algal blooms occur naturally and are not harmful, but a small percentage of algal species are harmful algal blooms (HABs) that can produce toxins that can cause illness or death in humans and marine organisms such as fish, seabirds, turtles, and dolphins. Some HABs are nontoxic to humans but are toxic to fish and invertebrates, damaging or clogging their gills causing hypoxia, or oxygen depletion, in the waters of marine environments. Dense blooms can also block sunlight for beneficial algae and sea grasses. [2]

HABs costs millions in damages and creates socioeconomic problems. It was estimated that the impacts of HABs costs at least $82 million in 2006. Much of the costs come from commercial fisheries and public health [3]. The toxins that get released by HABs will eventually make their way to larger organisms where the concentrations of toxins will build up in fish and shellfish. The higher level of toxins can force fisheries to throw away their product since it can no longer be eaten safely. HABs will also make it unsuitable for recreational activities like swimming and fishing, where people and animals would be around the water. Tourist areas would force tourists away, hurting the local businesses like restaurants, hotels, and retail stores. [4, 5]

Since the damages caused by algae growth cost millions each year, finding and stopping the algae growth would help reduce this cost. One of the tools currently used to find algal blooms are satellite imagery. With satellite imagery, large areas are able to be examined. The problem with satellite imagery, is that it does not have high enough resolution to give small level of detail. Also, it can be difficult predict where an algal bloom will occur, especially when the density of algae is low and in the beginning stages of growth. Another instrument that can be used is a CTD, also called sonde, which measure conductivity, temperature, and depth of the ocean. A CTD is collection of sensors put together onto a rig where it is slowly lowered into the water from a ship. CTDs are typically used for research to measure water quality. CTDs are able to make very accurate measurements at many different depths. CTDs cannot used as a remote sensor system since CTDs are typically tethered to the back of a ship and can only make measurements in a single specific location [6].

There are a few different methods that can be used to find algae. One way is to measure the amount of oxygen in the water. When algae exists, oxygen is introduced into the water through photosynthesis, but is consumed during the night [7]. Temperature can be used to help find algae, since warmer water temperature allows the possibility for algae to grow. Multispectral satellite imagery can be used to detect algae, since water and algae have different spectral signatures. Water is typically reflects little infrared light, but algae does. pH can be used as an indicator since photosynthesis removes carbon dioxide, which is slightly acidic in water, and increases the pH, meaning that there is less acid [8].

Purpose and Goals

This project attempts to combine the above tools into a solution that can be used to detect algae growth. By using multiple sensors in a distributed sensor network, deployed over a large area, it is able to gather data in a denser area than by satellite imagery and able to make more precise measurements similar to CTDs. At the expense less accuracy, lower cost sensors that cost a few hundred dollars can be used, whereas a single CTD sensor module can cost thousands. The sensors are only able to make measurement on the surface of the water, compared to CTDs which can make measurements of any depths with the help of the ship, but surface measurements will be acceptable since algae typically grows near the surface of the water.

The idea behind this is to help detect algae growth early on, so that preventative measures can be quickly put into place to limit or contain algae.

This project focuses on creating a platform to measure the marine environment. This platform is designed to measure data autonomously and send the data wirelessly back to a central computer. The main environmental sensor measurements to be made are the water’s temperature, dissolved oxygen levels, and pH levels. These measurements were selected due to the ease of obtaining such sensors from an online retailer and due to relatively lower cost, compared to other methods. The platform is powered by solar power and has an onboard battery to provide power at night or when there is not enough sunlight. All the electrical components are housed in a waterproof box, except the sensor probes and the solar panel. All the components are attached to a floating foam buoy, anchored to specific area.

Project Details

Block Diagram

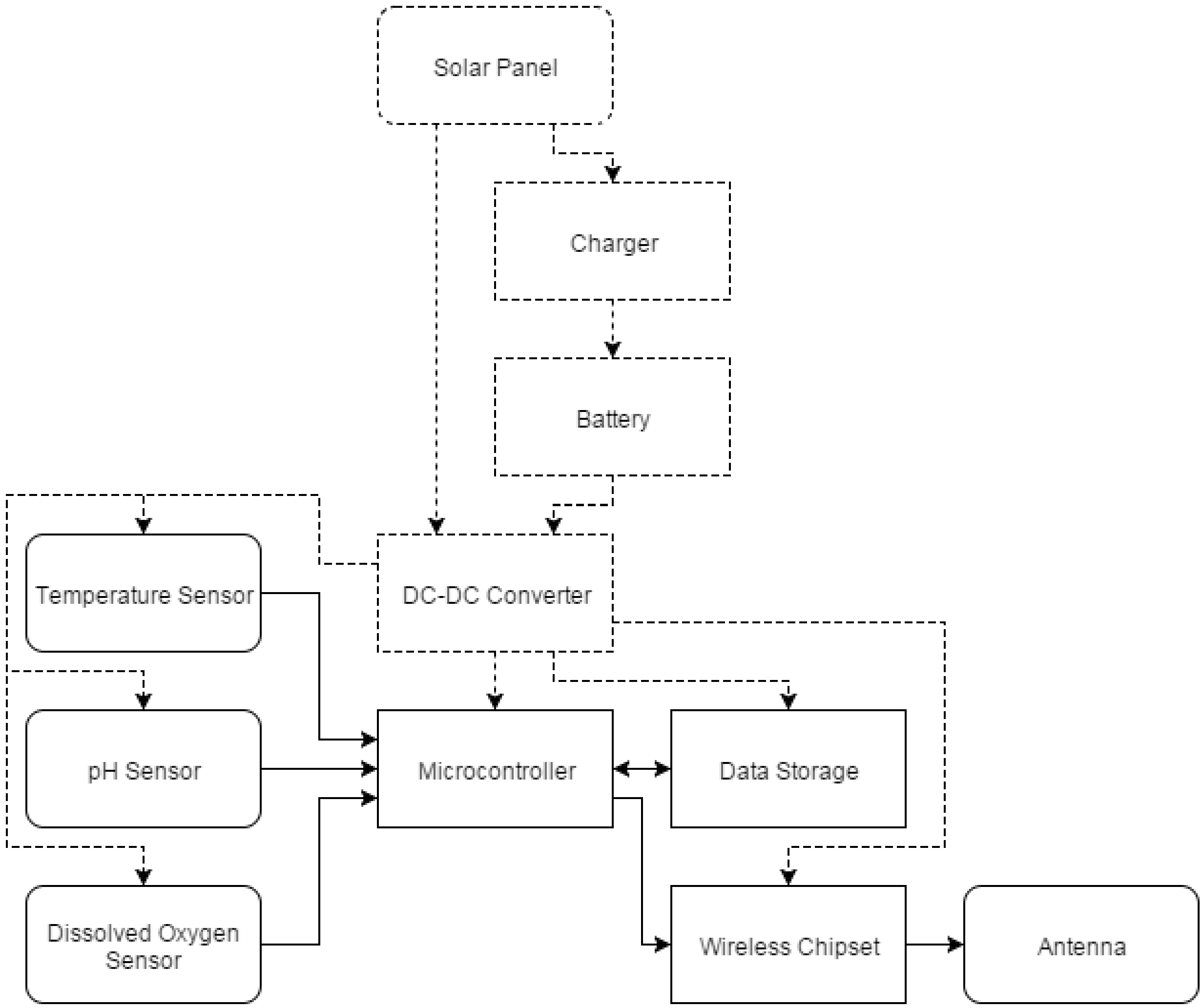

Figure 1: System block diagram

In the block diagram shown in Figure 1, the dashed lines represent power components of the system. The solid lines represents digital components. This system was designed to be primarily powered from a solar panel. The solar panel is used to power the entire system and charge the battery. A battery is included to provide power in the event of the solar panel is not providing enough power, due to factors such as cloud cover or time of day. A DC-DC converter is used to provide regulated power to all the sensors, the microcontroller, and the wireless chipset. The microcontroller is used as the logic to control when to gather data and to communicate with the other parts of the system. The three sensors are what measure the environmental parameters. The data from the sensors is sent to the microcontroller where the data is processed and saved on a flash data storage device. The wireless chipset is used when data is to be sent back to a host computer for analysis.

Part Selection

The microcontroller is a Texas Instruments MSP430F2252 [9]. It is a 16-bit microcontroller with 16kB of flash memory, 512 bytes of RAM and 32 GPIO pins. Included peripherals are an ADC, timers, and SPI/I2C/UART communication modules. This part was selected to be the microcontroller because it can operate using very little power, advertised as using 270 µA/MHz in an active state, has SPI and I2C protocol support, and has at least 16 GPIO pins for any ICs that need additional data lines or for debugging. Selecting a part from the MSP430 series of microcontrollers allowed me to reuse of existing development hardware I owned to help program and debug the microcontroller.

The temperature sensor selected is the Maxim DS18B20 digital thermometer [10]. It provides up to 0.0625°C resolution with ±0.5°C accuracy. This communicates with the microcontroller using the 1-Wire protocol. This sensor is available from Sparkfun Electronics as a waterproof probe and capable of being submerged. The primary reason this was selected is because the probe is waterproof and able to be submerged.

The pH sensor is from Atlas Scientific. Atlas Scientific have a pH kit, part number KIT-101P, which includes the pH sensor probe, pH measurement circuitry, and calibration solutions [11]. The Atlas Scientific measurement circuitry is connected to the microcontroller using the I2C protocol. The measurement probe is able to be submerged underwater, and provides scientific grade measurements. This part was selected because it is easily obtainable from Sparkfun Electronics, it includes the circuitry needed for the pH probe, and communicates using the I2C protocol that the microcontroller supports.

Similarly, the dissolved oxygen sensor is also from Atlas Scientific. The dissolved oxygen kit, part number KIT-103D, includes the dissolved oxygen sensor probe, dissolved oxygen measurement circuitry, and a calibration solution [12]. The measurement probe is able to be submerged underwater, and provides scientific grade measurements. This part was selected because it is easily obtainable from Sparkfun Electronics, it includes the circuitry needed for the dissolved oxygen probe, and it communicates using the I2C protocol that the microcontroller supports.

The wireless chipset selected was a Digi International XBee Pro S2C, part number XBP24CZ7UIT-004 [13]. This was selected due to its high TX power, which allows for long distance data transmission, it can connect to the microcontroller using the SPI protocol. This part also allows this system to use mesh networking, where multiple units can connect to each other and communicate without a direct unit to unit connection, which is a feature needed when this is used in a distributed sensor network.

The flash storage device is a Winbond W25Q128FV [14]. This is a 128 megabit (16 megabyte) serial flash memory arranged as 65,536 page x 256 byte format. This was selected because it has a large capacity to store many thousands of data points and communicates using a serial SPI protocol.

The figure below shows schematic of the sensors and the flash storage connected to the MSP430 microcontroller.

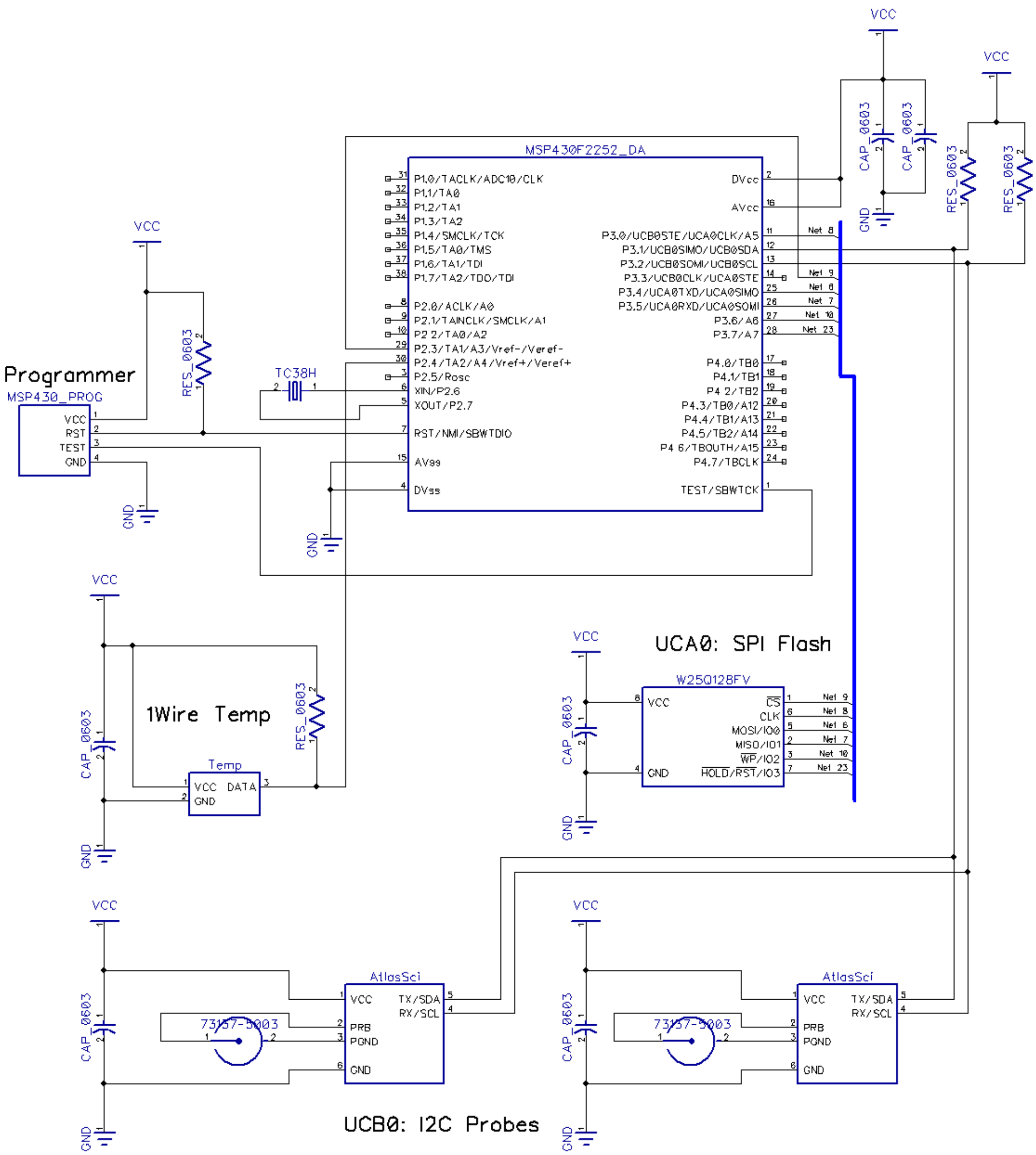

Figure 2: Schematic of microcontroller and sensors

The battery selected was a LiFePO4 battery from AA Portable Power Corp, part number LFP-26650-3300 [15]. The battery is a nominal 3.2V, a capacity of 3300mAh, and a max discharge rate of 19.8A. This battery chemistry was selected because it provides long life, estimated to be 10 years, and is designed to be very safe. LiFePO4 batteries are able to withstand more abuse, it terms of over discharging and over charging, without exploding or catching on fire. The battery specifications needed were to be able to provide power to the system for at least 24 hours and be able to output at least 60mA, meaning a capacity of at least 1440mAh is needed.

The solar panel was a generic solar panel obtained from eBay. It outputs a nominal 12V and up to 1.5W of power. This was selected because the output voltage is between 4.95V and 32V for the battery charger input.

The charger is a Linear Technology LT3652 [16]. This was selected because it is a battery charger compatible with the LiFePO4 chemistry and it uses a switching DC-DC converter topology. A switching DC-DC converter allows more efficient use of the power available from the solar panel, minimizing loss power through heat of linear power components [17].

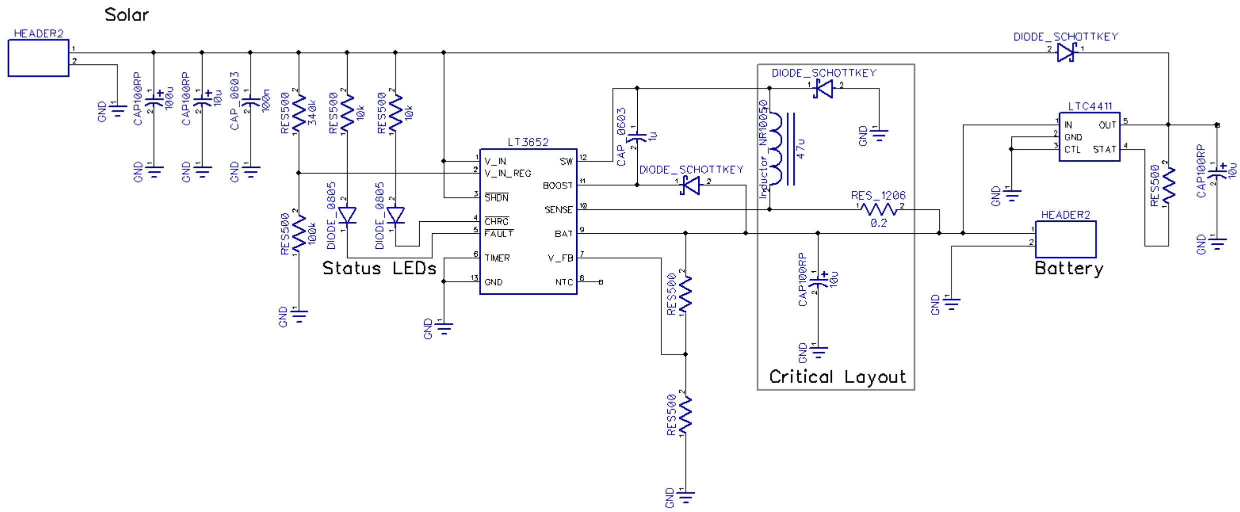

Figure 3: Schematic of battery charger and voltage selection circuit

The 3.3V DC-DC converter is a Linear Technology LTC3111 [18]. This part is a buck-boost DC-DC switching topology and provides regulated power to all the sensors, microcontroller, and storage. It was selected due its wide input voltage range, since the battery can go as low as 2.5V and the solar panel can go as high as 13V. Since the input voltage can be either above or below 3.3V, a buck-boost topology is used since it can support an input voltage that it is either above or below the output voltage.

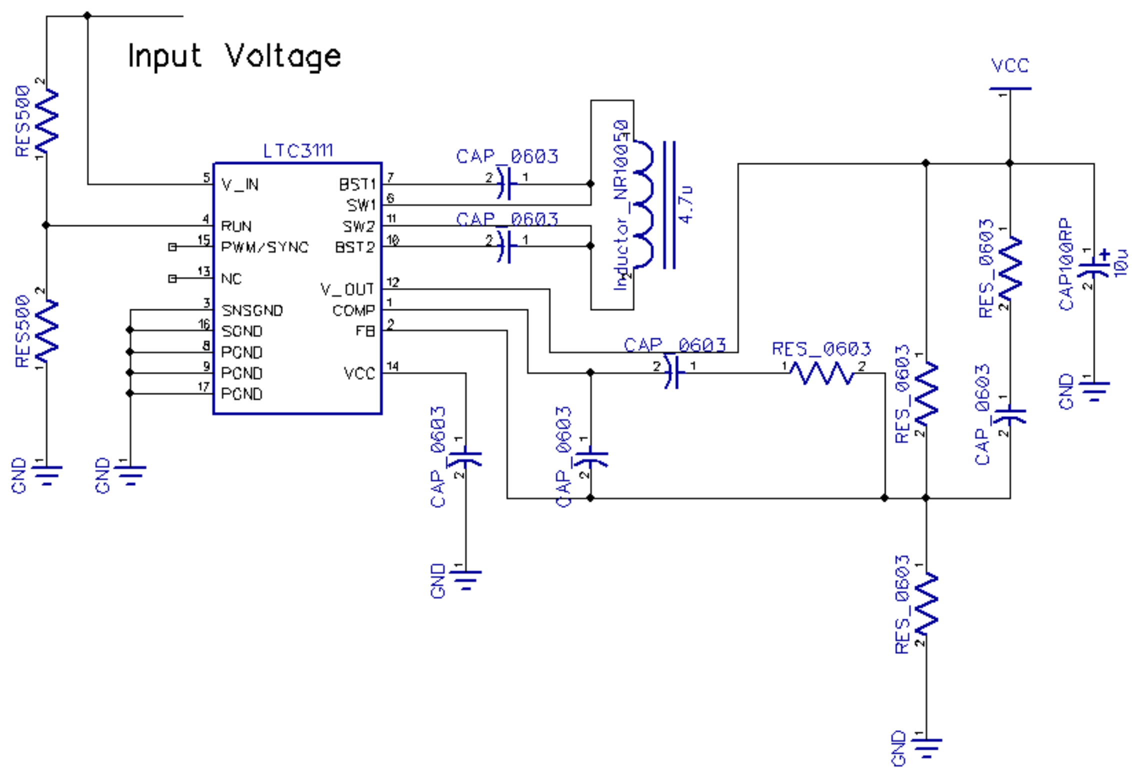

Figure 4: Schematic of 3.3V DC-DC voltage converter

Theory of Operation

States of Operation

The software is written to have a very simple state machine. The figure below shows how the states interact with each other.

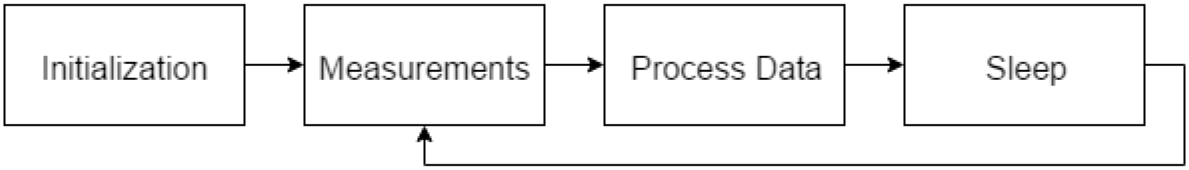

Figure 5: Software flow diagram

The initialization step, initialized all the microcontroller peripherals, the external ICs, and the storage header if needed.

The measurements are made every 10 minutes, timed using a 32.768 kHz watch crystal. Using the watch crystal gives better timing accuracy when compared to the timing accuracy of the MSP430's internal clock. A command is sent to each sensor, and the data is read back.

The data is then prepared to be saved into flash storage, by converting them from their original binary value into ASCII text. The conversion to ASCII text makes it easier to read the data when exported and allows the use of standard C string functions. The individual measurements are combined into a comma separated string, that is then saved into the next available storage address.

The system then goes into a low power mode, where almost everything in the microcontroller is turned off to save power. A timer waits 10 minutes before waking up and restarting the measurement cycle.

Storage Architecture

The storage used is a 16MB flash storage device, organized as 65536 x 256 bytes. This device communicates using the SPI protocol.

The memory storage format is a custom implementation that attempts to make an easy to use format for consecutive blocks of data less than 64 bytes in size. Memory is organized so that there is 4kB reserved for the header information and the rest for data. The header contains the address where data was last written to, and addresses of the last transmitted data points. Three bytes are needed for each address, in the format in the table below. The header uses 9 bytes total out of the available 4kB. Even though 4kB is more than enough space to store header information, the reason for this relatively large size is because an erase instruction erases 4kB worth of data. In order to update the header with new information, the old header must be erased, and a new header must be written.

Table 1: Header format

Address	0x000000	0x000001	0x000002	0x000003	0x000004	0x000005	0x000006	0x000007	0x000008
Header Data	Address of last data point			Beginning address of last transmitted data			Ending address of last transmitted data		
Big-Endian	MSB		LSB	MSB		LSB	MSB		LSB

After the header information, there are 64 byte blocks to store each data point. A data point is given 64 bytes, since it easily divides a 256 byte page, and it provides enough space to store an ASCII string of the data. The data points are stored in a comma separated format, detailed in the table below.

Table 2: Data format

Name	Value Type	Maximum Size (Bytes)
Reading ID	ASCII Text	6
Dissolved Oxygen Read Success	Boolean	1
Dissolved Oxygen %	ASCII Text	7
pH Read Success	Boolean	1
pH	ASCII Text	7
Temperature	ASCII Text	7

The data is stored in ASCII to make it easier to read the data when exported and read. If the data is stored in binary, less space is needed to store each data point, but additional software is needed to help convert the numbers into a readable format.

The table below summarizes the memory storage architecture when stored into flash memory.

Table 3: Memory storage architecture

Begin Address	Data		
	0x00	…	0xFF
0x000000	Header (4kB)		
…			
0x000F00			
0x001000	Data Each data point (64 bytes)		
…			
0xFFFF00			

Testing

Individual Sensors

Each sensor was tested individually to ensure correct operation and to perform any calibration if needed. The dissolved oxygen and pH sensors were calibrated with calibration solutions that came provided with the probes. The temperature sensor is calibrated against a multimeter's K-type thermocouple measurement.

Temperature Sensor

A temperature measurement at a few different temperatures were made using the temperature sensor probe and the multimeter's thermocouple. Room temperature water, warm water, and ice water were measured using the probe and thermocouple.

Procedure

1. Place both the probe and thermocouple into the room temperature water.
2. Wait until the readings stabilize to ensure thermal equilibrium of the probe and water.
3. Record the readings from the sensor probe and the thermocouple.
4. Repeat steps 1 to 3 for warm water and ice water measurements.

Dissolved Oxygen Sensor

The dissolved oxygen sensor was calibrated using the calibration solution that came provided with the dissolved oxygen sensor probe. The calibration is performed using two data points, one in atmospheric air and one in a solution with zero dissolved oxygen. This procedure is taken from the dissolved oxygen circuit's datasheet. The measurements from the dissolved oxygen sensor could not be compared to another dissolved oxygen instrument, so accuracy cannot be confirmed.

Procedure

1. Place the dissolved oxygen probe in open air.
2. Send the atmosphere calibration command to the dissolved oxygen measurement circuit.
3. Wait at least 1.3 seconds for calibration step to complete.
4. Place probe into solution of zero dissolved oxygen.
5. Send the zero dissolved calibration command to the dissolved oxygen measurement circuit.
6. Wait at least 1.3 seconds for calibration step to complete.
7. Take the probe and place in open air.
8. Measure the dissolved oxygen level. It should be near 100%.
9. Take the probe and place it into the calibration solution.
10. Measure the dissolved oxygen level. It should be near 0%.

pH Sensor

The pH sensor is calibrated using the provided set of calibration solutions that came with the pH sensor probe. The calibration is performed using 3 different pH solutions: 4.0, 7.0, and 10.0. This procedure is based off of the procedure in the pH circuit's datasheet.

Procedure

1. Place the pH sensor into the solution with pH 7.0.
2. Wait 2 minutes.
3. Send the calibration command associated with the solution's pH.
4. Wait at least 1.3 seconds for calibration step to complete.
5. Repeat steps 1 to 4 with the solutions of pH 4.0 and 10.0.

Charging Circuit

The charging circuit charges the internal LiFePO4 battery using power from the solar panel. The charging circuitry was tested by measuring the battery's charging current and monitoring the status outputs from the charger IC.

Procedure

1. Connect the battery and solar panel to the charging circuitry.
2. Measure the solar panel's voltage to ensure it is approximately 12V.
3. Ensure that the charging LED is on and the fault LED is off.
4. Measure the battery's charging current by measuring the voltage across the current shunt resistor. It should be approximately 15mA if the battery is not completely full.
5. Measure the battery's voltage. It should range from 2.5V to 3.5V.

Power Delivery

The power supply circuitry is tested to ensure that there is proper switching between battery power and solar power. The DC-DC voltage regulation is also tested to ensure proper output voltage.

Procedure

1. Connect solar panel connector to the PCB.
2. Ensure that power is being delivered to the 3.3V DC-DC regulator input.
3. Repeat steps 1 to 2, but with only the battery connected.
4. Connect both the solar panel and the battery to the PCB.
5. Measure the current from the battery and the solar panel. Battery current should not be discharging and the solar panel should be delivering the current.
6. Measure the output voltage of the DC-DC converter. It should be between 3.0V to 3.3V.

Storage

The storage system was tested to perform a few of the most common functions. The flash is erased, and test data is read and written to.

Procedure

1. Initialize the SPI flash device.
2. Erase all stored data.
3. Read the unique device ID and JEDEC ID.
4. Write the unique device ID and JEDEC ID to the flash storage.

5. Read back the written data.
6. Compare the data, and make sure it matches.

Whole System

The whole system was also tested as a unit. This was tested outdoors, where the electronics are tested to make sure they work in cold temperatures. The test uses a 5 gallon bucket of water as the measurement subject.

A prototype printed circuit board was created to hold all of the electronics and modules together. Below is a partial rendering of the first revision PCB.

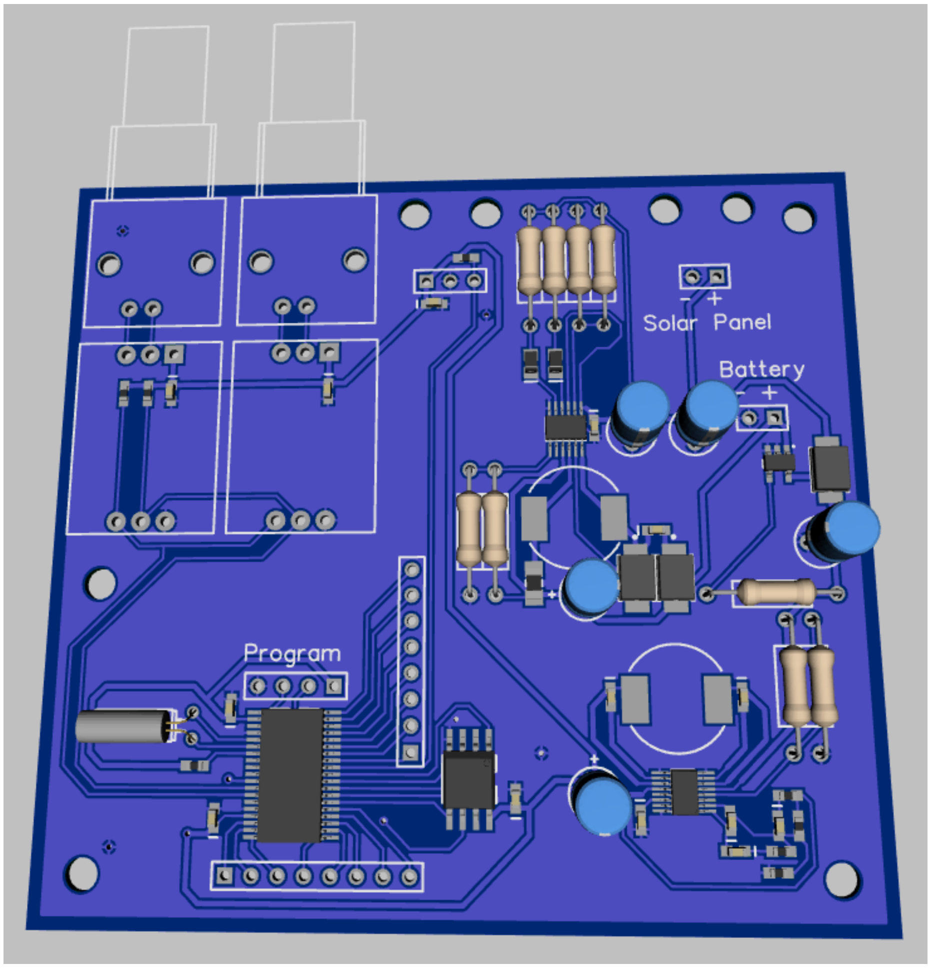

Figure 6: Rendering of PCB

Data

Measurement started on November 11, 2015 at 2:30 AM. Measurements were taken for three days, but the battery died in about 48 hours after the test was started. The data points for the dissolved oxygen sensor and pH sensor measured after 48 hours returned no data, suggesting that the Atlas Scientific circuits did not have enough power to continue operating. The temperature sensor continued working for a few hours, until it too stopped working.

The graphs below show the data gathered by the sensors.

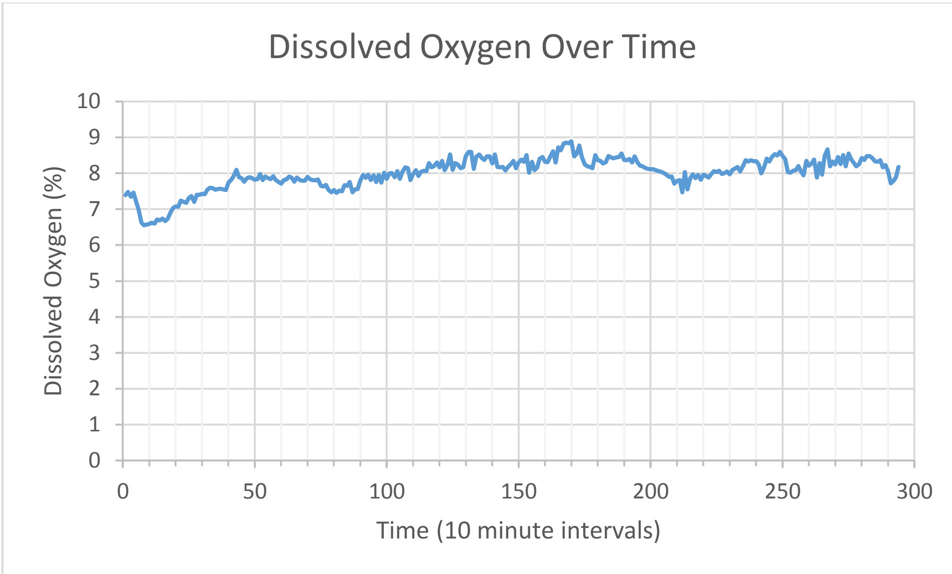

Figure 7: Dissolved oxygen over time

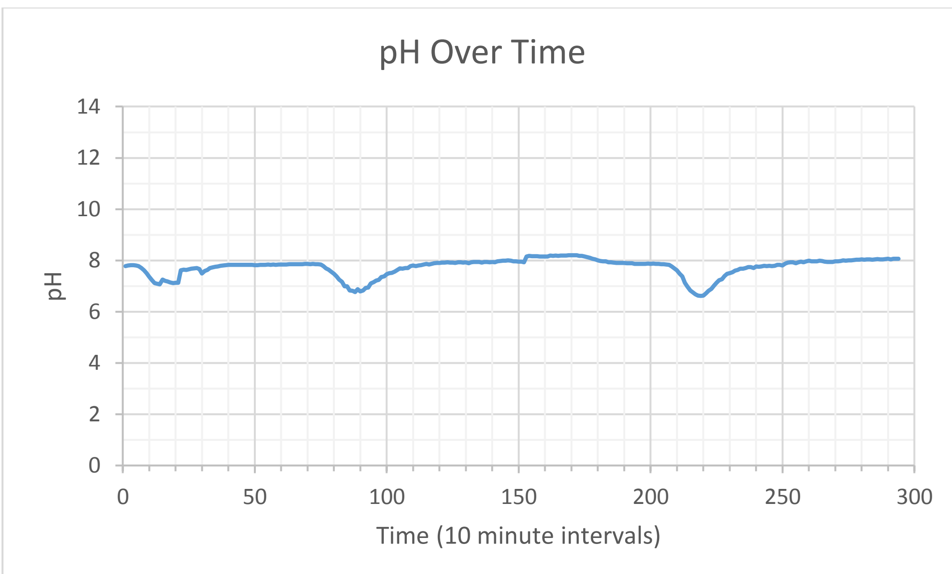

Figure 8: pH over time

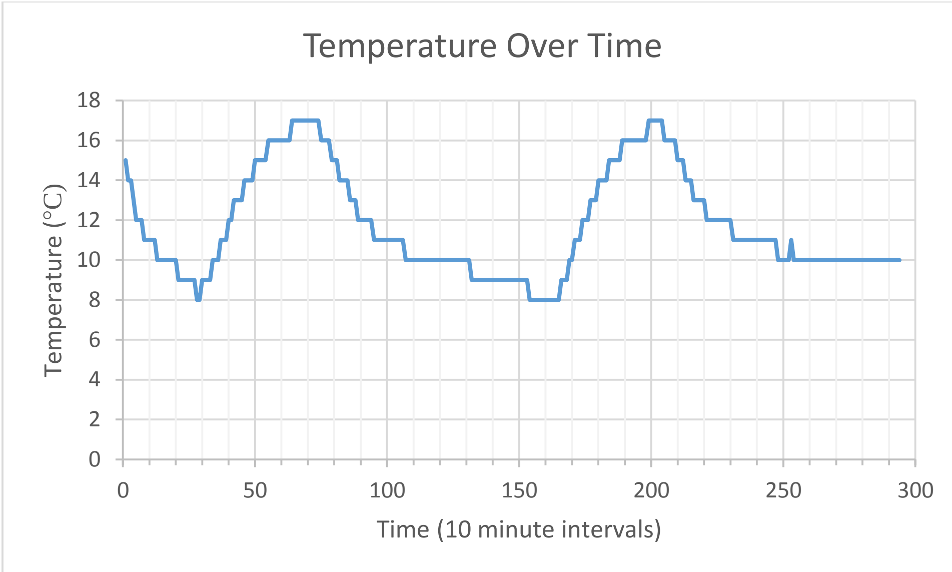

Figure 9: Temperature over time

Observations

In the dissolved oxygen graph, there is very little change, percentage wise over the maximum measurement range. There is however, a slight drop of roughly 0.5% over the course of the day time, and then returns back to a slightly higher dissolved oxygen content at night.

The pH graph shows that the water's pH is around 8. There are drops in pH when the temperature starts dropping, starting approximately after 2PM.

The temperature graph shows the water's temperature over the course of two days, which looks typical of a cold windy day when the data was measured. The water's temperature correlates to the air temperature over the day, where the water warms up in the morning, peaks somewhere between 10AM and 2PM, and slowly cools back down.

The system operated for about 48 hours before the batteries died, meaning that the solar panel was not providing enough power, the battery was not charging fast enough or at all, or the system itself is drawing more power than expected.

Conclusion

Overall Results

The system works, for the most part, but more testing is needed to test long term reliability and to find correlations between the data and algae growth. This has not been tested with live algae, due to the time of year, the algae do not have an optimal environment to grow in since the temperature is too cold, the body of water used for testing is not large enough, and the water does not mimic an actual body of water like a pond or the ocean.

Limits of Platform

There are several limitations of this platform that do not make it suitable for autonomous and continuous use.

The packaging of the whole system is not held together in an optimal way, especially since this is a currently a prototype. For example, the cables from the sensors entering the enclosure rely on a silicone sealant around the cables for a watertight enclosure. The sealant does provide a seal from the external elements, but long term sealing capabilities are not yet known to be reliable enough. Leaks may happen if the sealant loses its bond with the enclosure or the sealant deteriorates. The silicone sealant also makes it difficult to replace or service any cables, because it would require removing the silicone sealant around the cables to detach it from the connector on the PCB.

There are some issues, in terms of the power. It requires the solar panel to output a large voltage to meet input voltage requirements, especially when the solar panel is not outputting its full voltage when the sun is not directly shining. Another issue is that the 3.3V DC-DC converter and the charger components are not optimized to provide high power efficiency.

Future Improvements

A better connection system between the sensor cables and the enclosure would help make servicing easier. Currently, the cable's connectors are inside the enclosure to protect the connectors from the water. If the connectors were replaced with outdoor waterproof connectors, then it would reduce the chance of a leak happening in the silicone sealant and give this product a more professional look.

The power section of the system needs to be improved to provide better runtime before the batteries run out of power. Currently, the charger charges too slowly so when the night comes, the batteries are not charged enough to last through the night. Increasing the battery charge rate, as well as decreasing power consumed during idle, would help fix this issue.

The power section of this system is currently not as efficient as it could be. Improvements could include using two DC-DC regulators, one that can be disabled when not needed, and one always on DC-DC regulator.

Wireless communication is not setup yet, but the figure below shows a preliminary diagram of software flow. It shows an additional transmit data step, which is run if it has been greater than 24 hours since last transmission. Otherwise, it skips the transmission, and performs the next measurement.

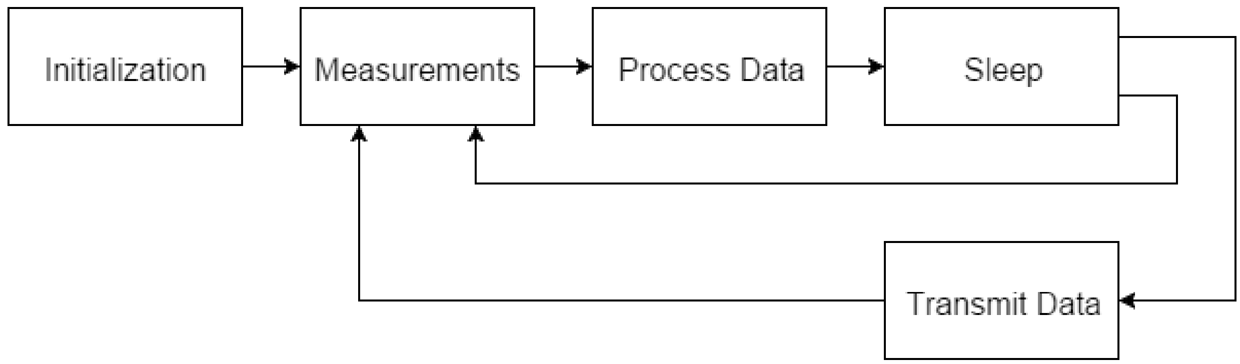

Figure 10: Software flow diagram including wireless communication

Appendix

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Analysis of Senior Project Design

Project Title: Platform for Environmental Sensing of Algae

Student’s Name: Alex Wu Student’s Signature:

Advisor’s Name: Andrew Danowitz Advisor’s Initials: Date:

- Summary of Functional Requirements
    - This is a platform used to measure environmental properties to potentially help determine if algae is growing in a specific area or not. It does this by measuring the water’s dissolved oxygen levels, pH levels, and temperature. This data is collected and wirelessly transmitted to a computer for analysis.
- Primary Constraints
    - A major difficulty was finding a way to waterproof the electronics from the outside world. A waterproof enclosure is easy to obtain, but adding ports for cables and connectors to pass through the enclosure makes it difficult to maintain the waterproof capability. Waterproof connectors were expensive and not suitable for my budget. A cheap solution was used which was to have the connectors internal to the enclosure, and using silicone sealant to create a seal between the enclosure and cable.
    - Another difficulty was trying to make the electronics behave reliability over the long term. Testing can be done over a short period of time, but testing for over a month is difficult, since it would require a dedicated test setup to monitor if anything fails.
    - Power usage is a constraint where it must consume very little power since solar power is the main energy source. Measuring multiple environmental parameters needs to consume as little power to maximize battery life.
- Economic
    - For the purposes of this project, premade sensors will be used to save money in development costs and speed up the development cycle. Material resources needed include plastics for the outer case, rubber and silicone for water protection, and metals and semiconductors for the electronics.

- Most of the costs will be up front during the development and manufacture of the sensors system. Some cost will come from yearly maintenance period where sensors need to be replaced or repaired or recalibrated, and from the cost of labor to manufacture and maintain the system. Below in Table 4 shows the estimated costs to manufacture a single sensor node. The cost will be lower if manufactured on a larger scale.

Table 4: Bill of Materials

Part Description	Manufacturer	Part Number	Quantity	Part Cost
MSP430 Microcontroller	Texas Instruments	MSP430F2252	1	4.91
Flash Storage	Winbond	W25Q128FV	1	1.78
Temperature Sensor	Maxim	DS18B20	1	9.95
Dissolved Oxygen Sensor	Atlas Scientific	KIT-103D	1	249.95
pH Sensor	Atlas Scientific	KIT-101P	1	129.95
Wireless Module	Digi International	XBP24CZ7UIT-004	1	28.50
Antenna	Laird	0600-00057	1	1.80
Battery Charger	Linear Technology	LT3652	1	7.16
3.3V Regulator	Linear Technology	LTC3111	1	7.69
Misc. Resistors	Generic [Rohm primarily]		18	0.40
Misc. SMD Capacitors	Generic [Samsung primarily]		14	0.32
Misc. Through Hole Capacitors	Generic		5	0.85
Misc. Inductors	Taiyo Yuden	NR10050T470M	2	1.98
32.768kHz Crystal	Abracon	AB38T-32.768KHZ	1	0.21
LEDs	OSRAM Opto Semiconductors	LG R971-KN-1	2	0.14
Diodes	STMicroelectronics	STPS140U	3	0.89
BNC Connectors	TE Connectivity	1-1337543-0	2	4.06
Battery	AA Portable Power Corp	LFP-26650-3300	1	7.50
Solar Panel	Generic		1	16.90
Case	Sparkfun Electronics	PRT-11366	1	8.95
		Total	59	483.89

- There were additional costs during the testing phase. There was a MSP430 development board, but this was obtained for free. A 5 gallon bucket of water, silicone sealant, foam mix cost about $50. There was the cost of shipping the components since many were ordered online, estimated to be about $50 total.
- The original development time of this project was estimated to be a year starting in October 2014. The actual development time was actually about 14 months, but about 4

months out of the 14 months as time spent not working on this project. After this project ends, further improvements listed in the conclusion could be worked on to help make this a more complete project, as well as to add functionality.

- If manufactured on a commercial basis:
    - The estimated number of devices sold per year would be in the low hundreds, assuming that there are multiple customers that would buy enough to cover about 100 square miles.
    - The estimated manufacturing cost for each device would be about $500.
    - The estimated purchase price for each device would be about $1000.
    - The estimated profit per year, assuming that 300 devices are sold would be $150000.
    - The estimated cost for user to operate device would be about a hundred a year for calibration solutions, the cost to deploy and retrieve the system, and yearly maintain ace.
- Environmental
    - This project is designed with a purpose to help protect the marine environment from being infested with algal blooms. This project uses the renewable resource, solar energy, as its main power source. This is designed to have minimal impact on the surrounding ecosystem around it and tries to be non-intrusive by having a small size. Problems would occur if large marine animals accidently eat or damage the sensor platform since the electronics would then deteriorate in the water.
- Manufacturability
    - The main issue when manufacturing this is keeping a watertight seal around all openings in the case. This is currently handled by using silicone sealant and rubber rings on the enclosure.
    - Everything needs to be mounted securely so that nothing would become loose or break off. In the water, there may be waves, so different components need to be securely attached.
- Sustainability
    - Issues with maintaining a sensor network include finding and retrieving previously deployed sensor nodes. There could be events where a sensor node could become lost and may need to be fitted with a GPS to help find it again. Upgrades that would improve the system would be to make it easily configurable. The resources needed to maintain the sensor system would be yearly calibration and cleaning if necessary.
- Ethical
    - Ethical problems of using this system would be that it may disrupt certain sensitive ecosystems by introducing a strange unknown object for animals tamper with. Animals may damage the sensors and release debris into the body of water.
- Health and Safety
    - There could be toxic materials used during manufacture such as lead, but if RoHS parts are used, the amount of toxic materials used is much less, since RoHS bans the use of certain toxic chemicals.
    - If the system is left untouched, there should be no health or safety concerns, assuming nothing leaches out of the casing. If the system gets damaged, debris may be released into the water.

- Social and Political
    - This project attempts to help the environment by helping protect organisms from being invaded by algal blooms. If algal blooms are detected, attempts can be made to stop the growth of damaging algae.
    - It may be possible to get support from local governments that are affected by algal blooms. Issues from this could be getting funding for implementing this project or if people do not want them.
- Development
    - During research on algae, I found out about the damages algal blooms can cause and the cost associated with them.
    - While looking for sensors, I learned about the tools available to measure the environment. In addition to the sensors I used, there are sensors for conductivity, color, water flow, and more.
    - I have gained greater insight on switching DC-DC converters, how they work, and the multiple topologies available. I was able to learn about the advantages and disadvantages of the different topologies and how the compare to a linear DC-DC voltage regulator.