Environmental Sensor Network Nodes

EE 496 Final Report
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Abstract:

The objective of this project is to improve the hardware of the third generation weatherbox modules by increasing functionality, data reliability, and ease of use. The fourth generation weatherbox has the added components of a real time clock and GPS which will be useful for tracking and organising data when the node network is implemented. Once a weatherbox module is deployed, it is expected to be a self sustaining device that provides accurate meteorological data for an extended period of time. The data collected from these boxes will assist in planning future renewable energy installations as well as provide data to be used in forecasting.

1. INTRODUCTION AND MOTIVATION

In 2012 almost 90% of Hawaii's electricity was produced using imported fossil fuels, resulting in the state having some of the highest electricity fees in the nation [15]. In order to lower these electricity costs, Hawaii must look toward more available and sustainable sources of energy. The Smart Campus Energy Lab (SCEL), operating under the Renewable Energy and Island Sustainability (REIS) program, aims to support a "greener" UH Manoa campus by creating and implementing technology that will assist with the planning of sustainable practices. One of the projects aimed towards achieving this goal is a weatherbox module that can collect and transmit environmental data. The weatherboxes, which are being designed and fabricated in SCEL, will be low cost, power efficient, and easily mass-produced so they can be widely used throughout campus. The data collected from these weatherboxes will be used to optimize planning of new renewable energy installations and ensure that they are implemented in the most beneficial way.

2. OBJECTIVE

The objective of the Smart Campus Energy Lab is to provide resources to assist with the implementation of sustainable energy practices at the University of Hawaii at Manoa. The focus of the Environmental Sensor Network Nodes project is to create a network of weatherboxes that span the university's campus and provide accurate meteorological data. These weatherboxes must be low cost, power efficient, and reliable so they can be placed throughout the campus. The data gathered by these boxes includes temperature, humidity, solar irradiance, and pressure; all of which will be transmitted to the SCEL server. Once the data is in the server, it will be used to forecast solar irradiance patterns.

The main objective for the Environmental Sensor Network Nodes project this semester was to improve the hardware of the third generation sensor module, also known as the Cranberry weatherbox. The objective was met by including a GPS and Real Time Clock in order to improve the overall functionality of the board. The main deliverable of the project was to produce a working Cranberry 4.0 board to deploy on the Holmes Hall roof. A second revision of the board was also created in order to clean up the board layout and implement changes to the board schematic. In order to complete the stated objectives within the semester, the team used the gantt chart shown in Figure 1 to remain on track.

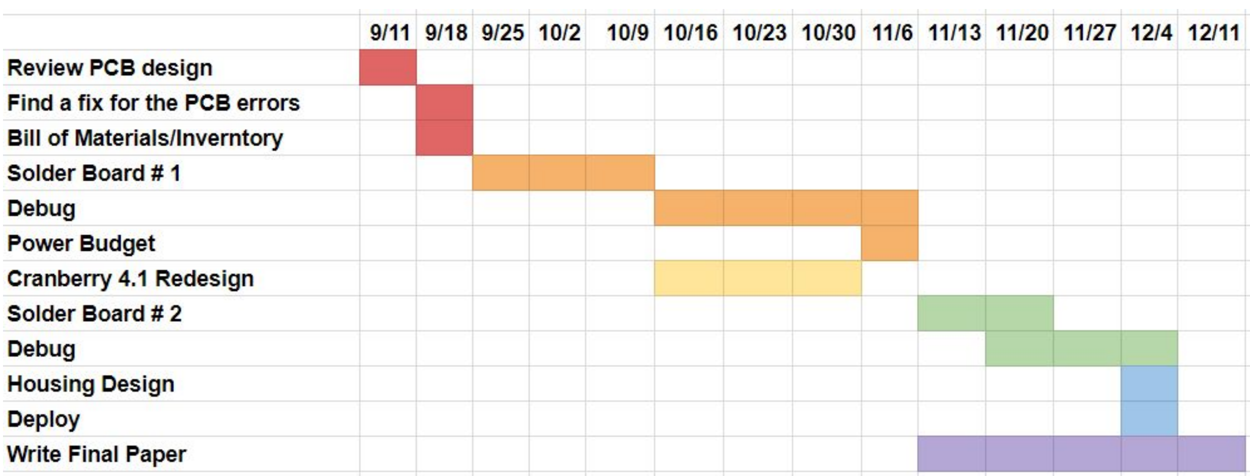


Figure 1: Gantt Chart for Fall 2017

3. HARDWARE DESIGN OVERVIEW

The main motivation for the design of Cranberry is to improve upon the hardware of the first generation weatherbox, Apple. This is accomplished mainly through the implementation of a more efficient power system and an overall reduction in size and cost. The Cranberry 4.0 module consists of two 2.375” x 2.375” printed circuit boards (PCBs) stacked upon each other. Stacked boards allow for both a reduced footprint and easier reparability than if the boards were connected. The main board contains the microcontroller unit (MCU) and XBee, and the sensor board contains the power system, weather sensors, and debug LEDs.

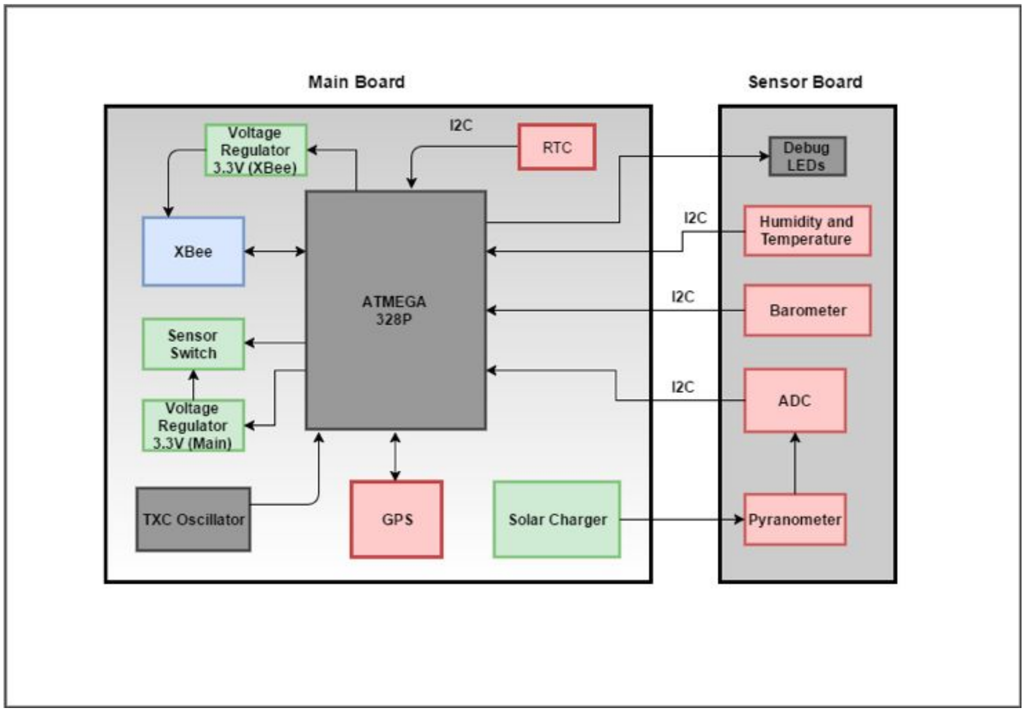


Figure 2: Main Board (left) and Sensor Board (right)

A hardware block diagram of Cranberry 4.0 is shown above in Figure 2, which shows the components and connections of the main and sensor boards. Although only the Cranberry 4.0 was worked on this the semester, the following boards describe the previous versions of Cranberry that were referenced in order to get to the current design:

- Cranberry *Version 3.2*

    - Designers: Brandon Amano and Kim Pee Castro (Completed: SP2016)
    - Significant redesign and overhaul of Cranberry board design
- Cranberry *Version 3.5*
    - Designers: Brandon Amano and Kim Pee Castro (Completed: SP2016)
    - Builds upon the design of Version 3.2 and incorporates fixes to several critical design flaws
- Cranberry *Version 4.0*
    - Designers: Jennifer Chun, Joslyn Hamada, and Emily Lum (Started: FA2016)
    - Builds upon the design of Version 3.5 and includes additional components for increased functionality
- Cranberry *Version 4.1*
    - Designers: Jennifer Chun, Joslyn Hamada, and Emily Lum (Started: FA2017)
    - Builds upon the design of Version 4.0 and includes wiring fixes and a change in layout for ease of use

3.1 Overview of Main Board

The main board is stacked on the sensor board and contains the microcontroller unit (MCU) and XBee transceiver. The following paragraphs will discuss both parts.

3.1.1 Microcontroller - ATMEGA328P

The main component of the Cranberry board is the ATMEGA328P microcontroller. The package chosen is a 32- pin VQFN, which operates on a supply voltage between 1.8V - 5.5 V. Although the ATMEGA already has a low current draw, the current draw was further limited by using an external quartz crystal oscillator to reduce the default 16MHz to 8MHz. The MCU includes twenty-three GPIO lines, and is I2C compatible. The pin outs of the MCU can be seen in Figure 3 below.

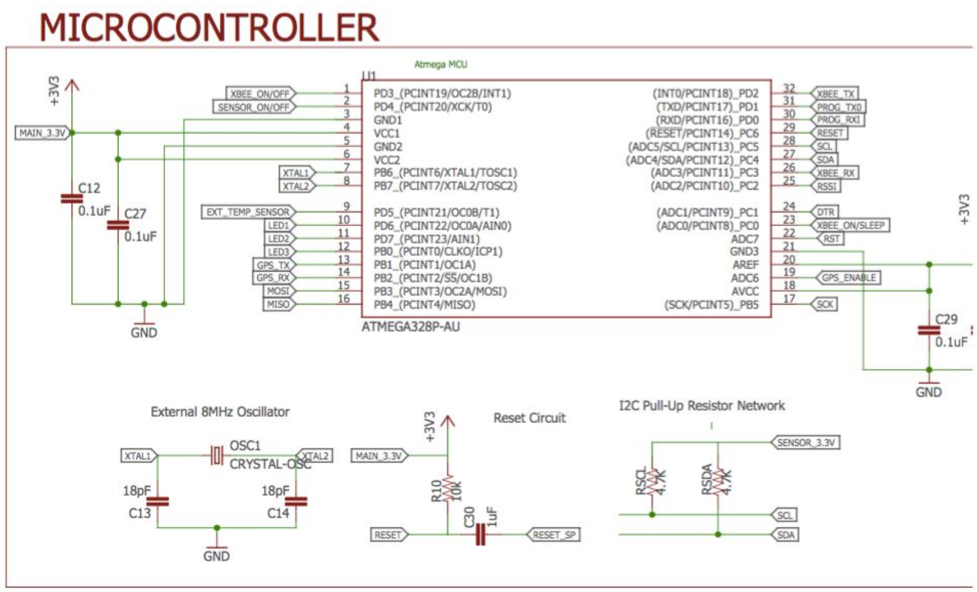


Figure 3: Microcontroller Unit Schematic

3.1.2 XBee Pro S2B Transceiver

The Cranberry weatherbox uses the XBee Pro S2B RF module, which operates using the ZigBee protocol. The XBee is meant to support low-cost, low- power wireless sensor networks. The main benefit of the XBee is that it requires minimal power while still providing reliable delivery of data. The XBee used by Cranberry operates in API mode, where data is wrapped in a packet structure that allows for addressing, parameter setting and packet delivery feedback.

3.2 Overview of Sensor Board

The sensor board is stacked on top of the main board and it contains the humidity, pressure, temperature, and solar irradiance sensors as well as the power system. The following paragraphs will discuss the specific sensors used by Cranberry, how the board is powered, and the newly added components.

3.2.1 Humidity and Temperature - HIH6131

Cranberry uses a single sensor, the HIH6131, to measure the humidity and temperature.

This sensor has a maximum error of +/- 4.0% which includes errors from non linearity and thermal and humidity hysteresis. One reason this error is kept so low because the component has a temperature compensation from 41 - 144 degrees fahrenheit which helps to ensure the accuracy of the readings. This component also has a low power consumption as it uses only 1 uA during sleep mode and 650 uA while taking measurements. The small package, low power consumption, and accurate measurements make this sensor very useful for the weatherbox.

3.2.2 Barometer - MPL115AT1

The MPL115A2T1 is a miniature digital barometer that has a measurement range of 50 - 115 kPa. It has a small package of 5 x 3 x 1.2 mm which is very useful when there is limited space. Another advantage of this device is the low power draw, 5 uA when active and 1 uA when in sleep mode. This component uses an integrated

ADC that converts the pressure and temperature to a digital output that is sent to the microcontroller using I2C.

3.2.3 Solar Irradiance - Apogee SP-212

Cranberry uses an Apogee SP 212 pyranometer which is a silicon cell photodiode that measures shortwave radiation. The solar radiation is taken in by the device, then is output as a cosine wave of 0-2.5 volts which is processed by the external ADC located on the sensor board. The data must be adjusted by a calibration factor of 0.5 W m^{-2} per mV to get the shortwave radiation in W m^{-2}. While the other weatherboxes can use either the SP 212 or the SP 215 (which outputs a signal of 0-5 v) Cranberry is limited to the 212.

3.2.4 ADC - ADS1115

The ADS1115 is a low-power, 16-bit analog-to-digital converter that is I2C compatible. One of the strengths of this design is that all of the sensors communicate with the MCU through I2C. While the barometer, humidity and temperature sensors all have an internal ADCs, the solar irradiance doesn't, so there is an external one (ADS1115) located on the sensor board. The external ADC is also capable of accepting data from several more sensors in the case that more components are added in the future.

3.2.5 Power

Most of the power system is located on the sensor board. It contains the DC jack to the solar panel, the solar charger, the battery, and the switches that control the power going to the sensors and debug LEDs. As previously mentioned, both boards run off of 3.3 volts which is provided by a 3.7 v lithium ion battery and a 6v solar panel. The solar panel voltage goes into a

MCP73871 solar charging chip which recharges the 3.7v battery every day. The battery voltage goes through the MIC5219 voltage regulators which drops voltage down to 3.3v which powers both the main and sensor board.

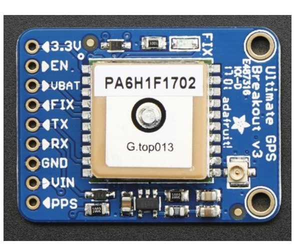
There are two switches (TPS27081A) on the sensor board which can control to voltage going to the sensors and the debug leds. The idea behind these switches is that they will be used to turn off the voltage going to unnecessary components in the case that battery voltage is low. This would reduce the overall power draw and give the weatherbox more time to recharge using the solar panel.

3.3 Newly Added Components

After comparing multiple GPSs and RTCs, these two were chosen because they were mid-priced, well documented, and breakout boards. For Cranberry 4.0, which was used as a prototype, headers were used to connect the two new parts to the main board in order to make soldering and testing these components easier. This was done because neither of these parts have been used by our team yet, so the flexibility of being able to test, remove, and change the parts will be helpful. During the redesign (Cranberry 4.1) the RTC breakout was replaced with a SMD component but the GPS remained as a breakout board.

3.3.1 GPS - Adafruit Ultimate GPS Breakout

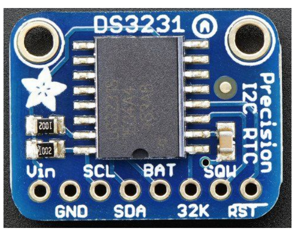
The Ultimate GPS Breakout will be used to keep track of the physical location of each



weatherbox by sending its position upon initialization. This board can be powered from 3.3v-5v if necessary as it has a 3.3 voltage regulator on it. However despite the low voltage use, the GPS has a high power consumption (about 20 mA) so it will be put to sleep after initialization. This will be done through the ENABLE pin which is controlled by the software in the microcontroller. The firmware for this particular GPS has already been written as Apple uses the same model, so implementation of it should be easy. It uses I2C to communicate with the MCU.

3.3.2 Real Time Clock - Adafruit DS3231 Precision RTC Breakout

The real time clock will be used to timestamp the relayed data which will be useful for organising data when the node network is implemented . The DS3231 uses an internal 32 kHz



timing crystal and temperature sensor. The advantage of having an internal temperature sensor located in the chip is that the component is able to account for slight changes in temperature, and therefore frequency, of the timing crystal. Both the internal clock and temperature sensor, ensures that the time remains accurate. The breakout board includes pinouts for Vin, GND, SCL,SDA, an external battery, a Reset to an external device, and a 32 kHz oscillator output. The last three pins listed aren't currently being used, but the SCL and SDA are the I2C pins that connect to the microcontroller.

3.4 Housing Design:

Cranberry 4.0's housing design is a 3D printed, weatherproof container with a focus of preventing water damage. As shown in Figure 4 and 5, the basic design is an upside down box with a separate compartment for the battery and two panels which connect the box to the solar panel. As this box is meant to keep water out, the housing is sheltered underneath the solar panel and has flaps covering the vents. Inside the box there are four 0.5 inch poles that are used to mount the PCB to the top of the box rather than placing the board on the bottom of the box. This was done to ensure that the board won't sit in any puddle of water that may enter the box (as has previously happened to Cranberry v3.5). The PCB was designed with one drill hole in each corner of the sensor board, these will be used to screw the board to the poles within the box. The hole, on the far side of the container shown in Figure 4, will allow the pyranometer, solar panel and XBee antenna to reach outside of the main housing. The top panels, as shown in Figure 5, will connect the box to the solar panels through screws. Then finally, the bottom will be screwed into the walls of the box.

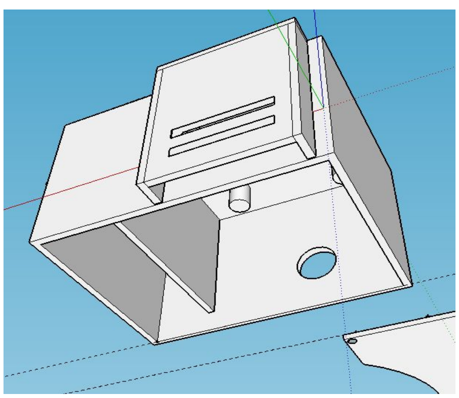


Figure 4: Cranberry 4.0 Housing

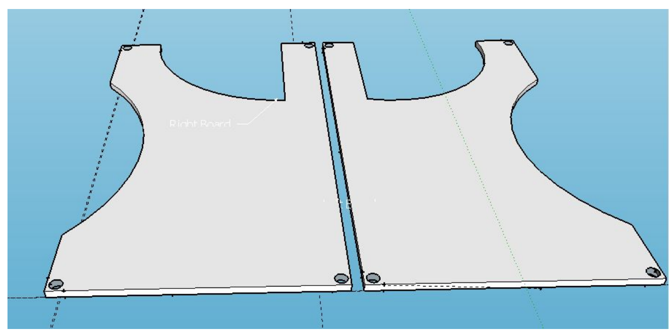


Figure 5: Panels Connecting Housing Box to Solar Panels

4. CRANBERRY HARDWARE TROUBLESHOOTING

4.1 Problems and Solutions

Throughout the semester there were several problems that occured while attempting to deploy Cranberry 4.0. The first problem occurred while populating a set of sensor and main boards. While most of Cranberry is made up of parts with 0805 packages, there are several components that have QFN packages such as the solar charger and the pressure sensor. Since the pins on QFN packages are located on the bottom of the device it is very difficult to solder these parts using soldering irons or heat guns. One way that these parts are typically soldered is by using a reflow station, which SCEL doesn't have. So in order to fix this, we asked other SCEL members to assist us with the use of a reflow station and were able to successfully solder the solar charger but not the pressure sensor.

Throughout the population of Cranberry 4.0, several issues with the board layout and design were discovered. One of these issues was that the package for the four paralleled 470 uF polarized capacitors attached to the solar panel were the wrong size. The package on the PCB was an 0805 which is far too small for the capacitor which is actually a 1206. Normally this could be fixed by ordering capacitors in the correct size, but a 4700 uF capacitor in a 0805 SMD package doesn't exist. Since a single 4700 uF capacitor is equivalent to four 470 uF capacitors, it was used as a replacement to fix this problem. The leads of a through hole 4700 uF capacitor was soldered to the correct ground and Vcc pads on the board. This is a temporary fix and will be addressed in the design of Cranberry 4.1.

Other problems found during the testing of Cranberry 4.0 were several issues with the wiring of the board. The errors were found while getting bad readings from the firmware. In order to troubleshoot the bad readings, the schematics of the board were compared with the datasheets and the schematics of Cranberry 3.5. Through this comparison, it was found that the battery voltage was not tied to the ADC and the solar panel was not tied to VCC. In order to fix this, the proper connections were manually routed, and continuity checks were performed to ensure that no shorts, cold solder joints, or bridged connections were present.

4.2 Debugging Tools

One tool that was very useful throughout the debugging process is the software Atom, which can be used to display data from the programmed board. Atom is a free and open source text editor that supports a variety of languages and can be run on Windows, Linux, or macOS. This semester an additional package called platformIO was used to build, upload, and show the results of the firmware for Cranberry. Once the board is correctly bootloaded and programmed, the output from the microcontroller can be seen on the serial monitor of the platformIO which we then use to debug Cranberry. The serial monitor shows all of the data gathered by the box: humidity, temperature, pressure, solar irradiance, battery voltage, and solar panel voltage.

The information provided by the serial monitor was used to assist with the debugging processes by helping to pinpoint the problems and possible causes. Seeing the real time data was helpful to see the effect of certain tests such as changing the board wiring or varying the light to the solar panel of solar irradiance. This helped to eliminate possible causes for wrong data values and narrow the focus towards other possible solutions. Most importantly provided another tool to assist in the debugging process so the firmware could be worked on without the software team.

4.3 Cranberry 4.1 Redesign

This semester, Cranberry 4.1, a redesign of the Cranberry 4.0 board, was created in order to address the concerns of the previously mentioned errors. For Cranberry 4.1, the capacitor packages were adjusted to the right size, and the wiring of the board was fixed on the PCB layout. The Real time Clock breakout board was also changed to a SMD component in order to have a cleaner layout. The population, debugging, and deployment of Cranberry 4.1 is expected to be completed in Spring 2018.

5. CRANBERRY WEATHERBOX DOCUMENTATION

As documentation was so heavily emphasized in previous Cranberry teams, there is a lot of information and documents already provided. In order to help future teams the documentation about the Cranberry design process, problems, and helpful hints were updated and uploaded to the wiki. This information includes the schematics and PCB layouts for both Cranberry revisions (4.0 and 4.1) as well as the bill of materials, power budget, and Cranberry 3.5 Eagle parts library.

A major design improvement for the Cranberry board is its significant increase in power efficiency and battery runtime. Listed below in Table 1 is the theoretical average and maximum current and power consumption of major Cranberry 4.0 components, as taken from their respective datasheets.

Table 1: Theoretical Power Budget for Cranberry 4.0

Cranberry Version 4.0 Power Budget			
3.3 Volt Module	**Datasheet Values**		
Device Name	**Idle (mA)**	**Typical Current Draw (mA)**	**Max Current Draw (mA)**
XBee Transmit	15.00	205.00	220.00
Barometer	0.01	0.01	0.01
Humidity (HIH6031)	0.00	0.65	1.00
V. Reg 3.3V (Main)		0.35	0.90
V. Reg 3.3V (Xbee)		0.35	0.90
Atmega 328P MCU	0.70	1.70	2.70
Irradiance ADC	0.01	0.15	0.30
Irradiance Op Amp		0.80	2.20
Adafruit GPS (MTK3339)		20	20
RTC (DS3231)	0.11		0.2
Total Current Draw (mA)	15.83	229.01	248.21
Supply Voltage (V)	3.30	3.30	3.30
Total Power Consumption (mW)	**52.23**	**755.72**	**819.08**

The current theoretical power budget is made with the assumptions that the sensors are polling for only half of the time and otherwise remain in the idle state, that leakage currents of the XBee module are negligible, that the XBee module is acting solely as a transmitter, and that 80% of the battery energy is usable before the battery cuts-out to protect against under-voltage. The following data shown below in Figure 6 was collected from Cranberry 3.5 after being deployed; however an actual power budget could not be created due to the short time that the box was on the roof. While an actual power budget could not be created, the power consumption of Cranberry 4.0 is expected to look like the power consumption of Cranberry 3.5 in Figure 6 since the new RTC and GPS (when idle) components have a very small current draw.

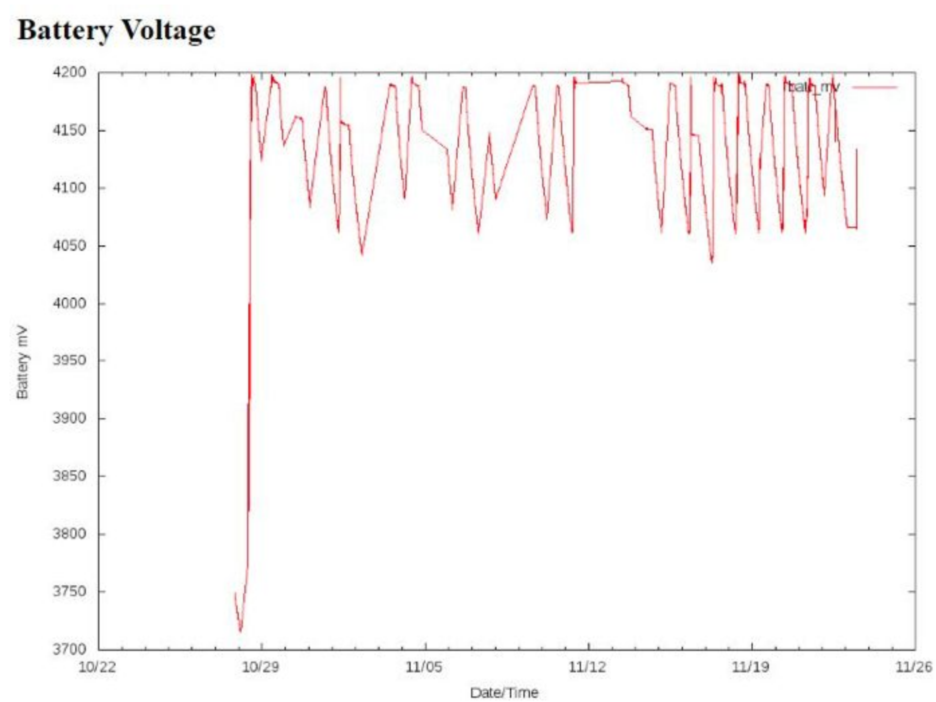


Figure 6: Cranberry 3.5 Power Consumption

The bill of materials (BOM) is an exhaustive list of components and hardware used in the Cranberry design. Information on part description, quantity, and unit cost is included with each material. The BOM includes all of the components required to implement the Cranberry 4.0, such as PCB manufacturing costs, weather sensors, and debugging and status LEDs. Excluding the cost of the ABS filament and hardware for the 3D printed housing, the total cost of a Cranberry 4.0 module is projected to be about $545.89. The BOM can be seen below in Table 2.

Table 2: Bill of Materials for Cranberry 4.0

#	Part Name	Unit Cost	Quantity	Sub-Total
1	Solar Irradiance Sensor	$235.00	1	$235.00
2	PCB Manufacturing Costs	$30.00	2	$60.00
3	6V Solar Panel	$59.00	1	$59.00
4	Solar Irradiance Leveling Plate	$35.00	1	$35.00
5	3.7V Lithium Ion battery	$29.00	1	$29.50
6	XBee Pro S2B	$29.00	1	$29.00
7	Humidity Sensor	$15.13	1	$15.13
8	Polarized 470 uF Decoupling Capacitors	$2.26	5	$11.30
9	External Temperature Sensor	$9.95	1	$9.95
10	Solar Irradiance ADC	$6.51	1	$6.51
11	Barometer Sensor	$5.10	1	$5.10
12	Status and Debugging LEDs	$0.38	12	$4.55
13	ATMEGA328P MCU	$3.70	1	$3.70
14	XBee Pin Headers	$1.48	2	$2.96
15	Polarized 2.2uF Decoupling Capacitors	$0.69	4	$2.76
16	Mechanical Sliding Switches	$1.37	2	$2.74
17	Miscellaneous Discrete Components			$17.74
18	Adafruit Ultimate GPS Breakout	$15.95	1	$15.95
19	RTC Module	$14.95	1	$14.95
	Cranberry v4.0 Total Cost			**$545.89**

6. INTER-TEAM COLLABORATION

Inter-team collaboration is extremely helpful for the debugging process, especially with the firmware team and fourth generation weatherbox team, also known as Dragonfruit. The firmware team provided insight on how to operate the applied XBee device. Cranberry is now able to send packets of data due to their help. The firmware team also helped with the programming of the MCU and making sure that the software was compatible with Cranberry. Communication with other generations of the wireless environmental module teams, primarily Dragon Fruit, also helped with the debugging process since the weatherbox generations are very similar to each other. The values obtained from Cranberry's solar irradiance were compared to those of Dragonfruit in order to debug the sensor readings.

7. FUTURE WORK

As of now one Cranberry 4.0 is able to gather, display and transmit the correct sensor readings, battery voltage, and solar panel voltage. The next step is to implement the GPS and real time clock. There is currently code written for the GPS, but not the real time clock so it may take some time to correctly write, debug, then implement the RTC firmware. After one Cranberry 4.0 is deployed and one is given to software, next semester will consist of populating and deploying Cranberry 4.1to build up the sensor node networks.

Once a weatherbox is successfully deployed, the performance of the board should be analyzed by conducting more tests and reviewing the received data. These tests would include an in depth power budget analysis, a test to see how long the box can support itself solely with the battery, and the results from an extended period of time on the roof gathering data.

8. CONCLUSION

The main objective of this project was to improve upon previous generations of Cranberry by increasing the functionality and data reliability. Once this was completed, by adding GPS and real time clock, the next goal was to deploy a Cranberry board to the roof of Holmes Hall. At the beginning of Fall 2017 the printed circuit boards arrived and the process of populating, debugging, and deploying began. Several unforeseen obstacles throughout the semester delayed the deployment of Cranberry 4.0, so it is still a work in progress. These problems mostly consisted of wiring issues which were found by reviewing schematics and using the software Atom to view the data from the board under different conditions. As of now there are two completely soldered Cranberry 4.0 boards. Both are programmed, give correct data readings, and transmit, but they don’t have the GPS or RTC, so they aren’t ready for deployment yet. The incorrect wirings in 4.0 was fixed during the design of 4.1 which will be sent out for fabrication over winter break and will be worked on throughout the Spring 2018 semester.

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