Final Report for Fall 2016 EE 396: Cranberry Weatherbox

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ABSTRACT:
The objective of the weatherbox project is to design and develop low-cost, accurate, and reliable environmental sensor modules that can easily be reproduced for mass deployment across the University of Hawaii at Manoa campus. The meteorological 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

The Smart Campus Energy Lab (SCEL) is a primarily student led lab within the Renewable Energy and Island Sustainability (REIS) program. SCEL's objective is to support a "greener" UH Manoa campus by creating and implementing technology that assists with the planning of sustainable practices. One of the projects aimed towards achieving this goal is the weatherbox module which will 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 it can be widely used throughout campus. By gathering data from the entire campus, it will be easier to plan where new renewable energy installations such as solar panels should be implemented in the most beneficial way.

2. MOTIVATION

It is clear that Hawaii needs to begin utilizing the many renewable energy sources available to us. In 2012 almost 90% of Hawaii's electricity was produced using imported fossil fuels, resulting in Hawaii having some of the highest electricity fees in the nation. By reducing our dependence on imported oil and looking toward renewable energy sources, Hawaii's economy and environment will benefit. One of the downfalls of renewable energy such as solar and wind is that they aren't constant and therefore they aren't completely reliable. Using the data from the weatherboxes, the solar irradiance patterns can be predicted and adjusted for accordingly so there is less risk when using renewable energy sources.

3. OBJECTIVE

The objective of the Smart Campus Energy Lab is to create a network of weatherbox modules that spans the university's campus and provides 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 goal for this semester was to deploy the current version of the weatherbox, known as Cranberry 3.5, and to improve the printed circuit board. The most recent version (3.5) was designed and populated in Spring 2016 but was not tested or deployed. Once Cranberry is completed, the redesign of the board will be aimed at reducing power consumption, improving board layout, and adding new sensors/parts.

4. 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 weather module consists of two 2” x 2” printed circuit boards (PCBs) stacked upon each other. In addition to the reduced footprint of the weather module, stacked boards allow for easier reparability than if the boards were connected. The main board contains the microcontroller unit (MCU), XBee, and power components, while the sensor board contains the weather sensors and the debug LEDs. Although there were not many design choices made for Cranberry in the Fall 2016 semester, there will be several new design choices made for Cranberry 4.0 in the Spring 2017 semester.

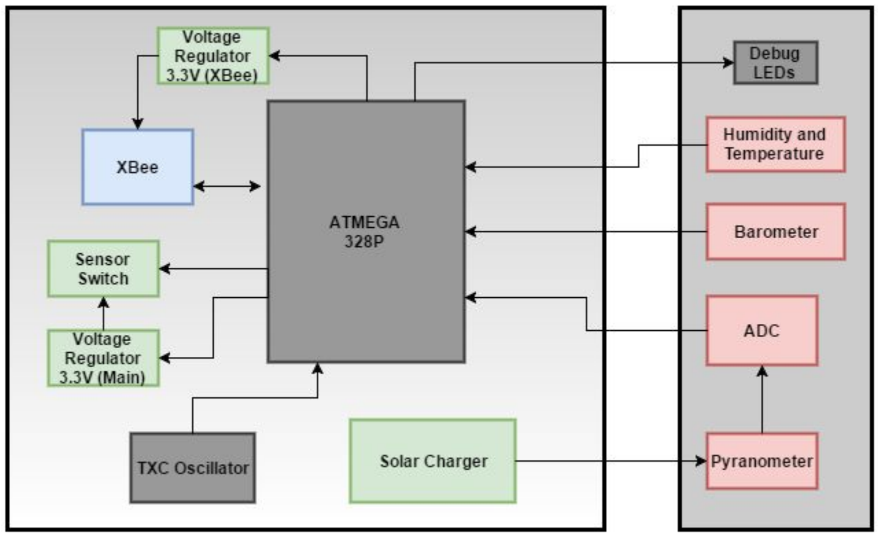

Figure 4.1 Main Board (left) and Sensor Board (right)

A hardware block diagram of Cranberry 3.5 is shown above in Figure 4.1, which shows the components and connections of the main and sensor boards. Although only the block diagram of Cranberry 3.5 is shown, the following boards were all worked on at some point during the Fall 2016 semester:

- 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 revisions as discussed in section 8 of this paper

5. CRANBERRY WEATHERBOX DOCUMENTATION

A major design improvement for the Cranberry board is its significant increase in power efficiency and battery runtime. Listed below in Table 5.1 are average and maximum current and power consumption of major Cranberry 3.5 components, as taken from their respective datasheets.

Table 5.1 Power Budget for Cranberry 3.5

Cranberry Version 3.5 Power Budget

3.3 Volt Module	Datasheet Values			XBee Characteristics	
Device Name	**Idle (mA)**	**Typical Current Draw (mA)**	**Max Current Draw (mA)**	**Transmit Time**	**Idle Time**
XBee Transmit	15.00	205.00	220.00	0.0109%	99.9891%
XBee Recieve					
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		
Total Current Draw (mA)	15.72	209.01	228.01		
Supply Voltage (V)	3.30	3.30	3.30		
Total Power Consumption (mW)	**51.86**	**689.72**	**752.42**		

Rechargeable Li-Po Batteries (3.7V)

Battery	Voltage (V)	Current (mAH)	Useable Energy (%)
6600 mAH Li-ion 3.7V	3.7	6600	80.0%

Estimated Battery Running Time

Battery	Energy (mWH)	V. Reg Efficiency (%)	Max Power Consuption (mW)	Max (Hrs)	Max w/ V. Reg Efficiency (Hrs)
6600 mAH Li-ion 3.7V	19536	80.0%	75.99	257.1	205.67

After considering all of the major components, the total system consumption is calculated to be a maximum of 75.99mW with an estimated battery run time of 257.1 hours. The current 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 5.1 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.

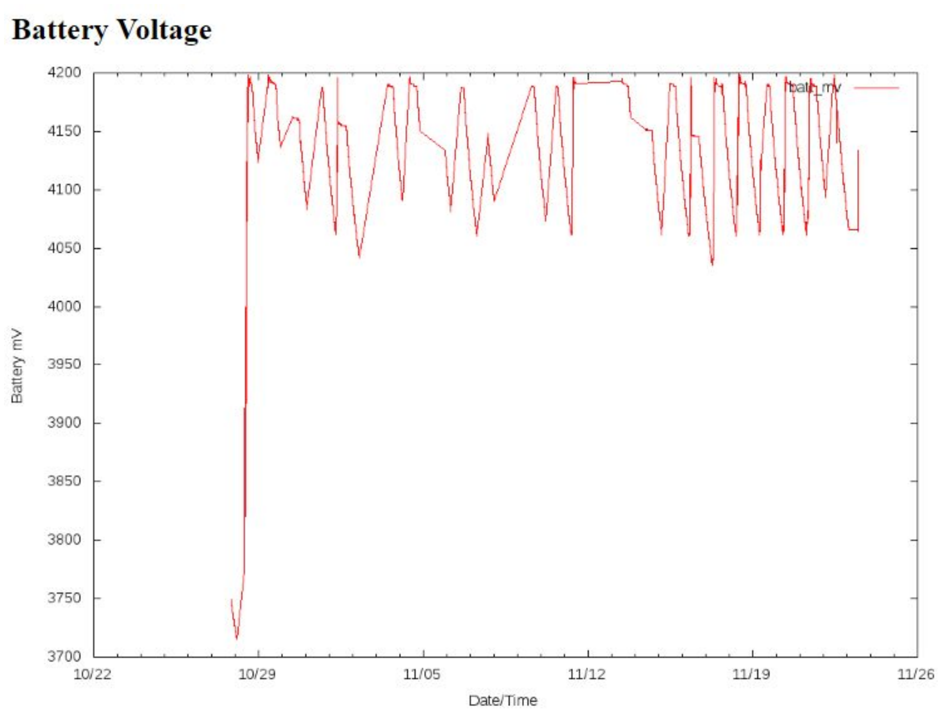

Figure 5.1 Cranberry 3.5 Power Consumption

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 3.5, such as PCB manufacturing costs, weather sensors, and debugging and status LEDs. Recent, significant changes to the BOM for Cranberry 4.0 reflect the addition of a GPS sensor, which will be discussed in section 8 of this paper. Excluding the cost of the ABS filament and hardware for the 3D printed housing, the total cost of a Cranberry 3.5 weatherbox is calculated to be $529.94, and the total cost of a Cranberry 4.0 weatherbox is projected to be about $604.89, not including the PCB resizing costs. The BOM can be seen below in Table 5.2.

Table 5.2 Bill of Materials for Cranberry 3.5 and 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
	Cranberry v3.5 Total Cost			**$529.94**
18	GPS Module Copernicus II DIP	$74.95	1	$74.95
	Cranberry v4.0 Possible Total Cost			**$604.89**

For the new Cranberry 4.0 redesign, we had to make a new parts library and redesign a new schematic. We received the parts library that Kim and Brandon made, and were recommended that we make our own parts for experience. We made all of the symbols, but only a few packages, as measuring package dimensions were taking too long. Because we're using the same components as Cranberry v3.5, the only changes made to the schematic were the inclusion of the GPS. Shown in the figure below is the first page of the schematic for Cranberry v4.0.

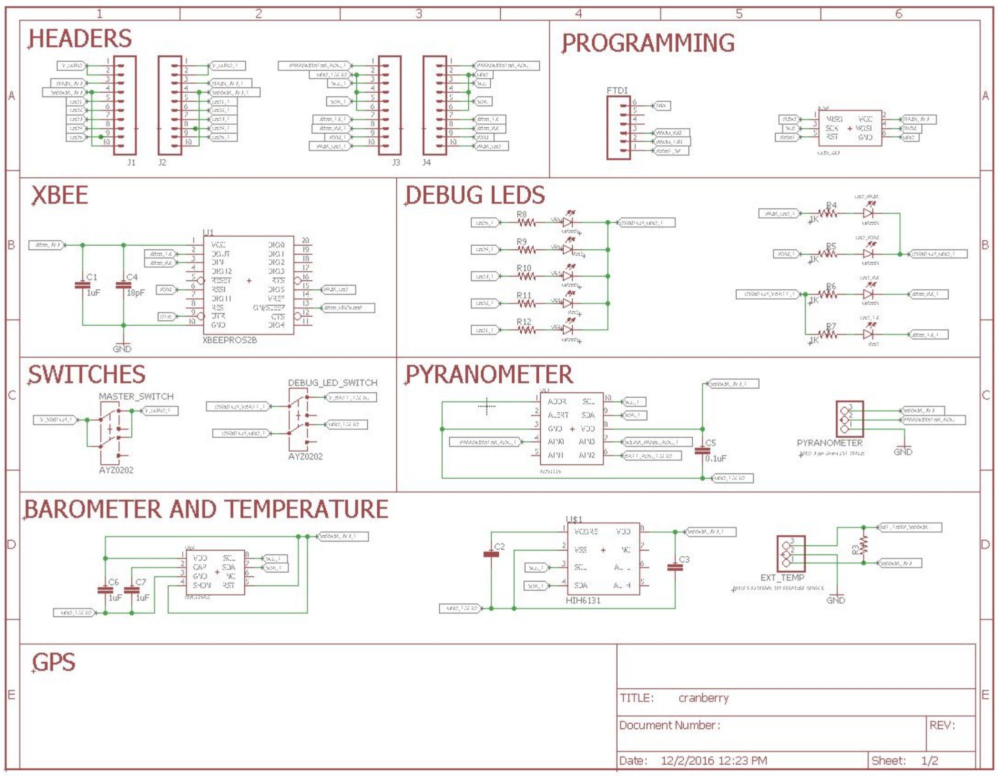

Figure 5.2 Cranberry v4.0 Schematic

6. HARDWARE TROUBLESHOOTING

At the time of the PDR presentation, Team Cranberry had worked on three boards, Cranberry 3.2, Cranberry 3.5, and Cranberry 3.5 Red. However, after working a little with all of the boards, the team decided to work primarily on Cranberry 3.5 Red as it was the closest to being ready to deploy. The following problems and solutions refer to the Cranberry 3.5 Red board.

Cranberry 3.5 Red originally did not program at all. It was discovered that the problem was due to having a clock that was out of sync with the board. In order to fix this, the board's 16MHz clock was desoldered and replaced with an 8 MHz clock. Once that happened, the board could be programmed; however, the firmware would stop reading data at the pressure sensor. Although the team initially supposed that a new pressure sensor was needed, it was later revealed that the error was due to a floating pin. After getting past the pressure sensor in the firmware, readings were received from all of the sensors except for the solar irradiance. The solar irradiance sensor originally could not be tested because a new sensor had to be crimped with the correct wire order. When that was done, the solar irradiance values were received with the wrong scaling; however, that was easily fixed with the help of the firmware team.

After all the sensors started working properly with correct scaling factors and proper readings, we needed to test the Xbee to see if it could send and receive data packets successfully. Unfortunately, the Xbee wasn't working. We initially didn't know what the problem could've been, then Tyrin was testing it with the multimeter and found that there was no voltage going to the Xbee. We tried resoldering the voltage regulator connected to the Xbee, but still no results. After a couple of days of troubleshooting, Kenny found that there was an enable pin on the Xbee that was tied to the Xbee ON/OFF pin on the microcontroller. The software team then turned it on in their code, and found that there was also a floating pin on the voltage regulator. After resoldering and turning the enable pin to high, the Xbee was transmitting and receiving successfully.

There was also a problem with the battery voltage reading. We weren't getting the correct readings due to the scaling factor. We tried different ways of changing it, and eventually we found a scaling factor that worked using a voltage divider, but we had no explanation as to why it worked. With help from other teams, we realized that the schematic had two different resistor values, when the board had two resistors of same value. This explains why the scaling factor we chose was correct, as it matched the voltage divider result.

After waterproofing our housing and putting all the parts together, we successfully deployed Cranberry v3.5 Red. After a week, the temperature started giving a negative reading due to overflow. The problem was quickly resolved when software team retrieved Cranberry v3.5 Red from the roof and successfully reprogrammed it.

On one stormy day, our deployed box stopped transmitting data to the SCEL server. Software team went to the roof to investigate and it was found that our solar panel and cover flew off the box, exposing our board to rain and wind. We immediately dried it off and left it alone for a day. The next day, we tested it and everything was working fine, so we think it stopped transmitting data because something was disconnected when the cover flew off. Before our board gets redeployed, we still need to make final adjustments to housing so that it'll be resistant to strong winds.

7. ACCOMPLISHED WORK

As of now, one Cranberry 3.5 was successfully deployed that transmits accurate, real time environmental data. Once that was completed, the redesign of the Cranberry 4.0 PCB began and we began populating a second Cranberry 3.5 board for deployment by the end of the year.

8. FUTURE IMPROVEMENTS

Although Cranberry 3.5 was deployed this semester, there are still many tasks that need to be completed. One of the main goals for the Spring semester is the redesign and deployment of the Cranberry board. There are several improvements planned for Cranberry 3.5 (this new version will be referred to as Cranberry 4.0). One of the challenges that occurred while deploying the 3.5 was the size of the board which was 2'' x 2''. The compact design made it hard to debug efficiently, so the 4.0 will be increased to 2.5'' x 2.5'' in order to make the redesigning, soldering, and debugging easier.

Another reason for the increased board size is to accommodate the additional sensors that will be added. Since Cranberry 3.5 is so power efficient, there will be a GPS, real time clock, and external temperature sensor added to the 4.0.The GPS is a Copernicus II (12 Channel) module connected to a breakout board and requires an external antenna. This GPS has a real time clock and a standby mode, which will reduce current and power consumption. It will be connected through header pins rather than a surface mount, which will increase the amount of available space on the board. In addition to these changes, the housing design will be improved so it is more durable and waterproof. Once the design of Cranberry 4.0 is completed, it will be printed, populated, and deployed by the end of the year.

Depending on the battery voltage reading of the 4.0, once it has been deployed, additional sensors may be added. Several sensors that may be useful are wind, rain, or UV sensors. As we are unsure of how much power the GPS and external temperature sensor will actually use, all future improvements will be made based on power consumption and available space on the board.

9. CONCLUSION

Since the beginning of the semester, one weatherbox (using the Cranberry 3.5 board) was successfully deployed and the printed circuit board for Cranberry 4.0 began. Though we encountered several problems throughout this semester, mostly caused by our unfamiliarity with the board, it was a good learning experience and we were able to improve both our technical and soft skills.

REFERENCES:

1. B. Amano and K.P. Castro. “WIP: Wireless Environmental Sensor Module Generation 3” University of Hawaiʻi at Mānoa. Dec. 2015, revised May 2016. ▯
2. "Smart Campus Energy Lab Wiki." *Weatherbox:start [Smart Campus Energy Lab Wiki]*. N.p., 17 July 2015. Web. 17 Dec. 2016.