Beverage Coaster with Sensing Capabilities

ECE 445 Design Document

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Group 61
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2/22/18

1 Introduction

1.1 Objective

IoT and smart connected devices have been successfully infiltrating the food & consumer services market. These devices can o provide restaurants the ability to monitor chefs, food preparation time and identify & limit inefficiencies [1]. Connected devices in restaurants have a slight overhead cost of getting started but the value that they provide to both the customer and management far exceeds its initial investment [2]. Using these smart devices also provides insights to management that could not have been benchmarked before. Using specific sensors and data collection mechanism, software is better able to track and organize data so that trends and conclusions can be made to better serve people. These trends could have to do with saving costs, time or being better prepared during peak hours [3].
It is our goal to tap into this smart sensing IOT market and produce something worth using in the restaurant space. Restaurants compete in a very competitive food services industry where innovation is needed to acquire and retain customers.

By producing a beverage coaster with sensing capabilities, we are entering the restaurant IOT market space that can be transformed through the ability to collect useful beverage consumption data and enact better service protocols from the beverage coaster data.

1.2 Background

When considering this project, we looked at other projects that were similar in line to the idea we were thinking. A group came up with a coaster that protects your drinks at bars. This bluetooth enabled coaster connects to your phone and notifies you if someone tampers with your drink when you enable the feature. This works by putting the coaster on top of the drink and motion sensors [4]. This device is available for purchase at $39.99, showing that there is a viable market for these types of enhanced coasters.

We felt that the solution of putting the coaster on top of the drink is stupid and felt that it can be more useful if the drink always sat on top of the coaster. Our goal is to produce a more affordable coaster that instead uses it weight sensing capabilities to send accurate liquid information to a central hub that management can use to service tables in a priority queue style.

1.3 High Level Requirements

- The coaster should be able to accurately measure the weight of the cup and its drink which should be around 6-9 lbs.
- The coaster should be able to transmit that data once every minute at 2.4 GHz using the bluetooth protocol to a central hub for analysis and determine who needs service via a queueing protocol.
- The coaster should remain low cost; ideally it should be around $40

2 Design

Our coaster requires five main modules: a control module, a communication unit, a sensor unit, a power supply and a central hub. The power supply will be a small coin cell battery that can fit inside the form factor of the coaster and power the other three modules and provide 5V. The control unit will handle collection of data from the load sensor as well as storage of the average weight in the storage. The communication module will collect the data to be transmitted through bluetooth from the control unit to a central hub. The central hub will collect data from all coasters in the vicinity that are on and determine if any drinks are empty or almost empty and alert any necessary restaurant staff which drinks might be empty and need refills.

For the physical design of the coaster, we are looking to make a cylindrical coaster that has a radius of 55 mms and a height of 20 mms, and the weight sensor as well as the Bluetooth Module and coin cell battery should be embedded inside of the coaster. The coaster will be 3D printed using such that the PCB designed will fit in the base of the coaster which will house

Physical Design

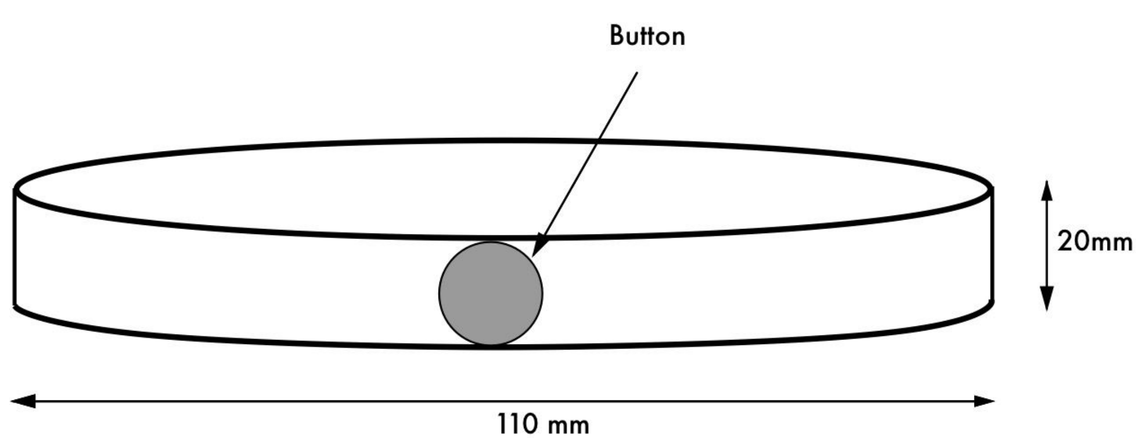

Figure 1 . Coaster Side View

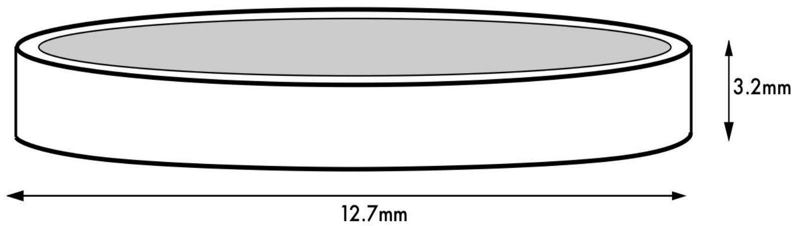

Figure 2 . Battery Side View

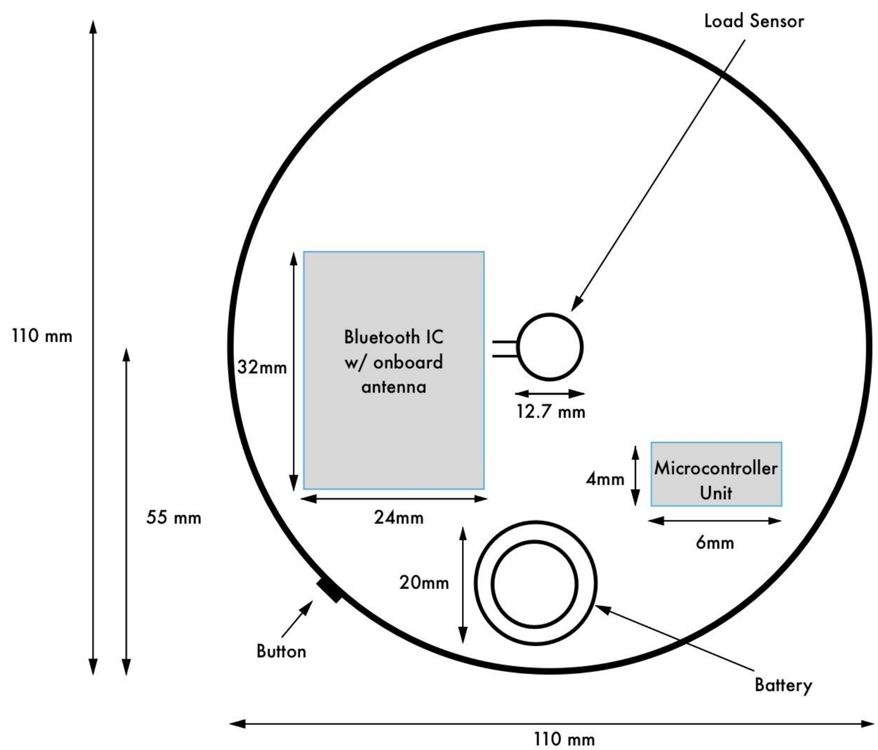

Figure 3 . Coaster Overview (not to scale)

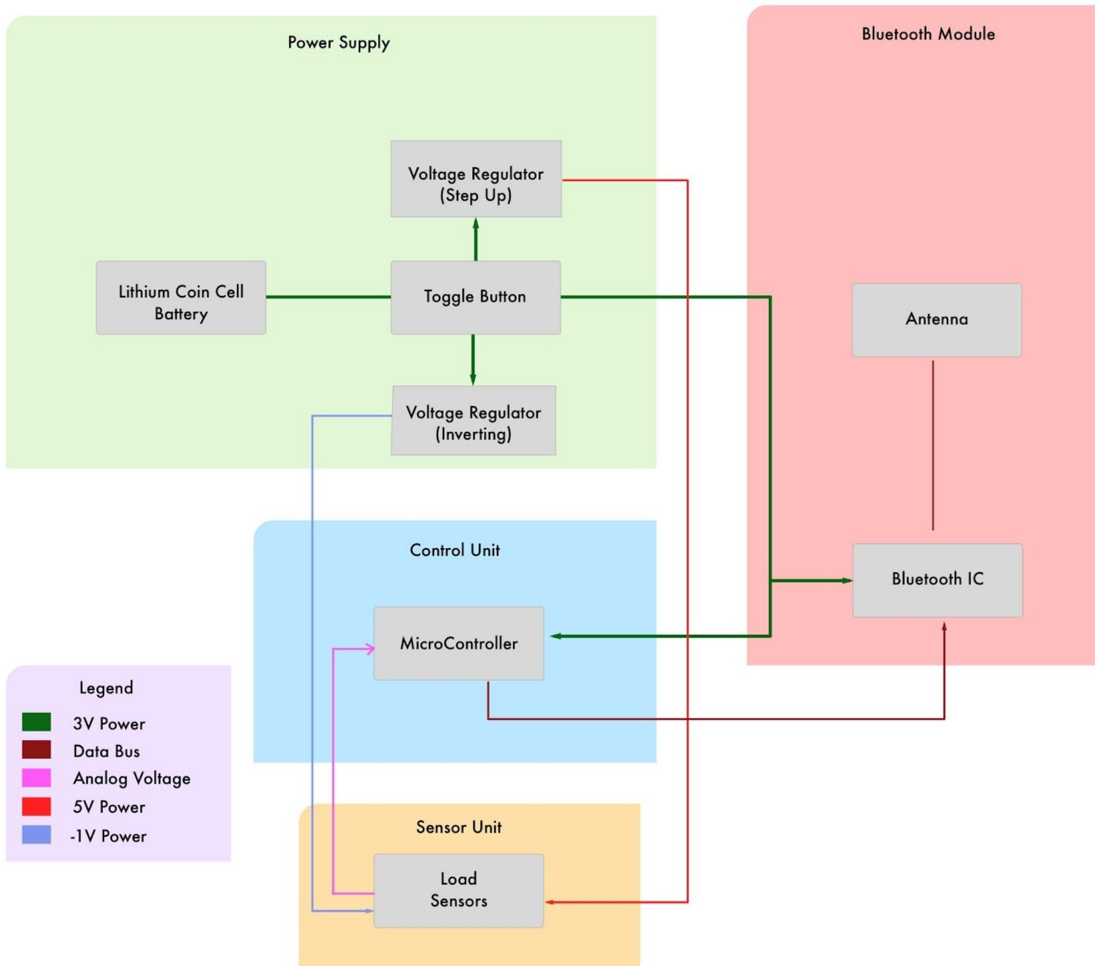

Figure 4 . Block Diagram of Coaster

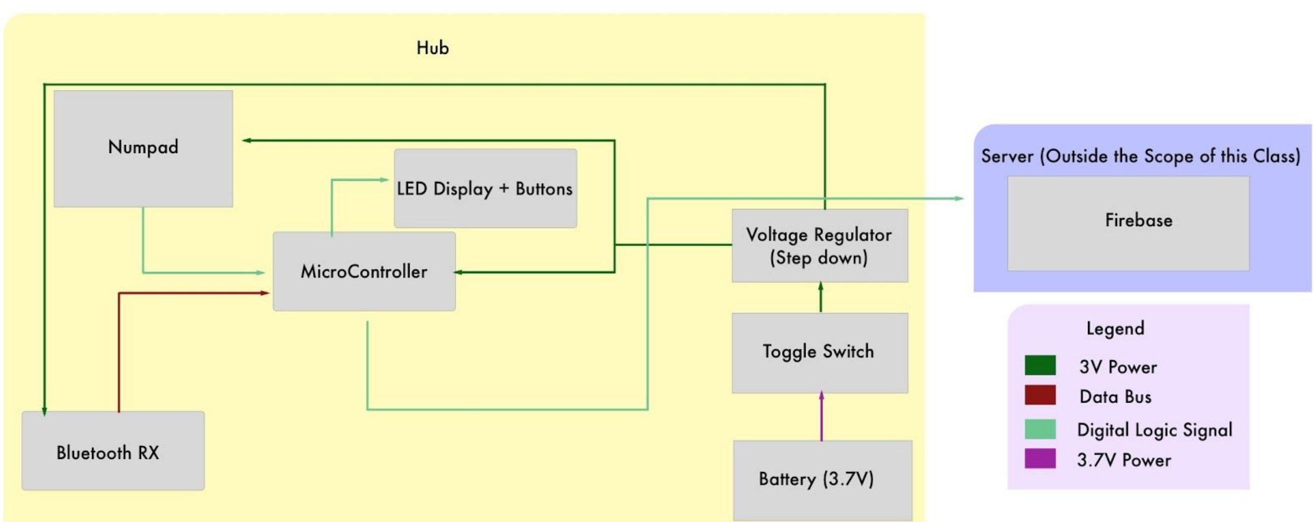

Figure 5. Block Diagram of Hub

2.1 Control Module

The control unit will control the sensor operation as well as the storage of its previous measurements on flash storage so that we can have an average weight over a certain period. On top of that, the control unit will also control the bluetooth module and determine when to transmit data to the hub.

2.1.1 Microcontroller

The microcontroller will collect data from the load sensor via an analog voltage and convert that into a 10-bit digital signal. It will convert that 10-bit signal into a weight and add it to the current average weight in flash storage. Once a minute passes, our microcontroller should prepare the data to be sent out to the bluetooth IC using the bluetooth protocol.

Requirements	Verifications
1. Ensure that the microcontroller can send out signals to the bluetooth IC for bluetooth communication 2. Ensure that the microcontroller has a GPIO pin that can read an analog voltage of up to 3 Volts with accuracy of 10%	1. a. Prepare a basic signal to be sent out from the microcontroller to the IC antenna b. Using another antenna for receiving, confirm we receive the same signal original sent out 2. a. Use a power supply to provide different voltages to the GPIO pin b. Have microcontroller display analog voltage reading on terminal c. Confirm that analog voltage is within threshold

2.2 Sensor Module

The sensor unit will collect the weight of the drink currently sitting atop the coaster

2.2.1 Load Sensor

A flat membrane load sensor will be placed at the top layer of the coaster will and collect the weight of the drink and send its reading to the microcontroller. The load sensor we plan on using is the FlexiForce A401 sensor. For the FlexiForce A401 Sensor, we can weigh from a range of 0.2 to 7000 lbs. depending on how we power the sensor. We have chosen to feed the negative terminal of the sensor with -1V which should currently give us a voltage range of 0.2-25 lbs. On top of the negative lead voltage, there is a feedback resistor in the circuit that helps determine the range of weights we would like to measure. By adjusting this resistance, we can either increase the force range or decrease the force range. There was no specific way given to convert analog voltage to a specific weight, so we plan to fully characterize the sensor once we do get it so we can determine a relationship to use as compared to the basic plot shown in figure 7 which we got from the datasheet. Once we characterize the sensor, we can determine the resistance that would allow us to use the sensor in the range we want.

Requirements	Verifications
1. The load sensor should be able to track the weight of 7.5 lb. glass cup with up to 1.25 lbs. of liquid in it within 5% of the actual weight	1. a. We can measure a cup with some amount of liquid and its specific amount on a digital scale b. Then we can measure the same cup with the same amount of liquid c. Using our microcontroller, we can read the analog voltage d. Convert the analog voltage to weight and compare it to digital scale reading

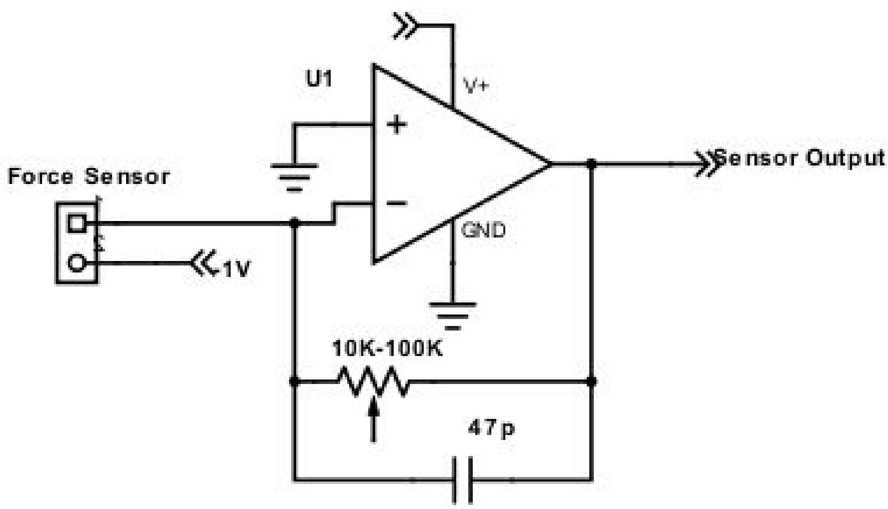

Figure 6 . Force Sensor

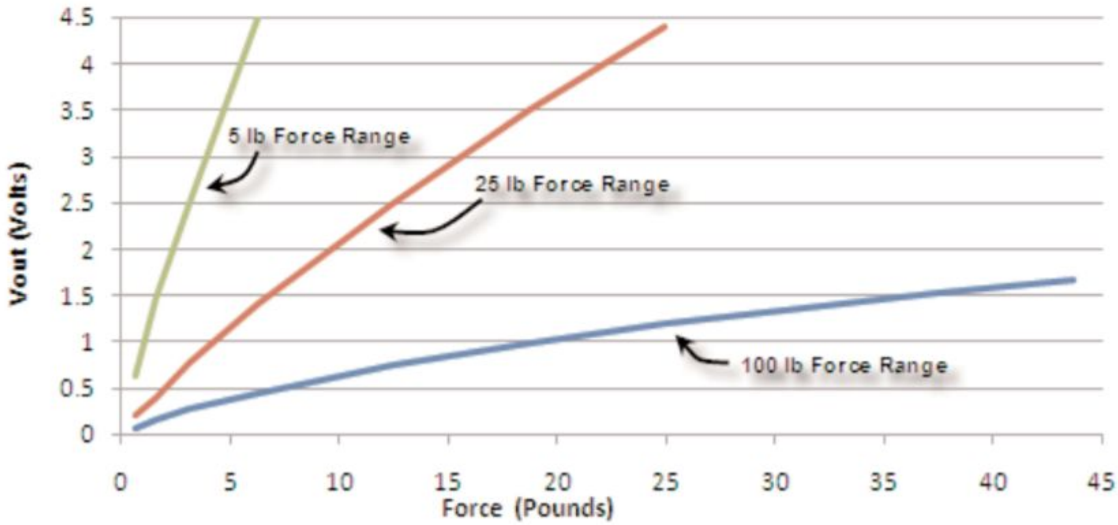

Figure 7 . Load Sensor Voltage Output

2.3 Bluetooth Module

The average weight which should be stored on flash memory from the microcontroller will be sent to the communication module for transmission.

2.3.1 Bluetooth IC

The Microcontroller will communicate with the bluetooth IC through a data bus and the bluetooth IC will then transmit the weight to our central hub via the antenna

Requirements	Verifications
1. The IC should be able to transmit a bluetooth signal at 2.4 GHz to the antenna	1. Program the IC to transmit a basic signal at 2.4 GHz through the antenna and confirm that signal is received at another receive

2.3.2 Antenna

The Microcontroller will communicate with our hub through a PCB trace antenna at a frequency of 2.4 GHz. We currently plan to use an inverted F-type antenna that will be matched to the antenna port output of our microcontroller.

Requirements	Verifications
1. The antenna should be matched to 50Ω±5% around the frequency of 2.4 GHz 2. The antenna should have a range of 18-22 meters	1. Using a network analyzer and a coaxial cable, test the antenna match 2. a. Program the IC to transmit a signal. b. With a Bluetooth Receiver, confirm we can still receive the bluetooth signal within the specified range

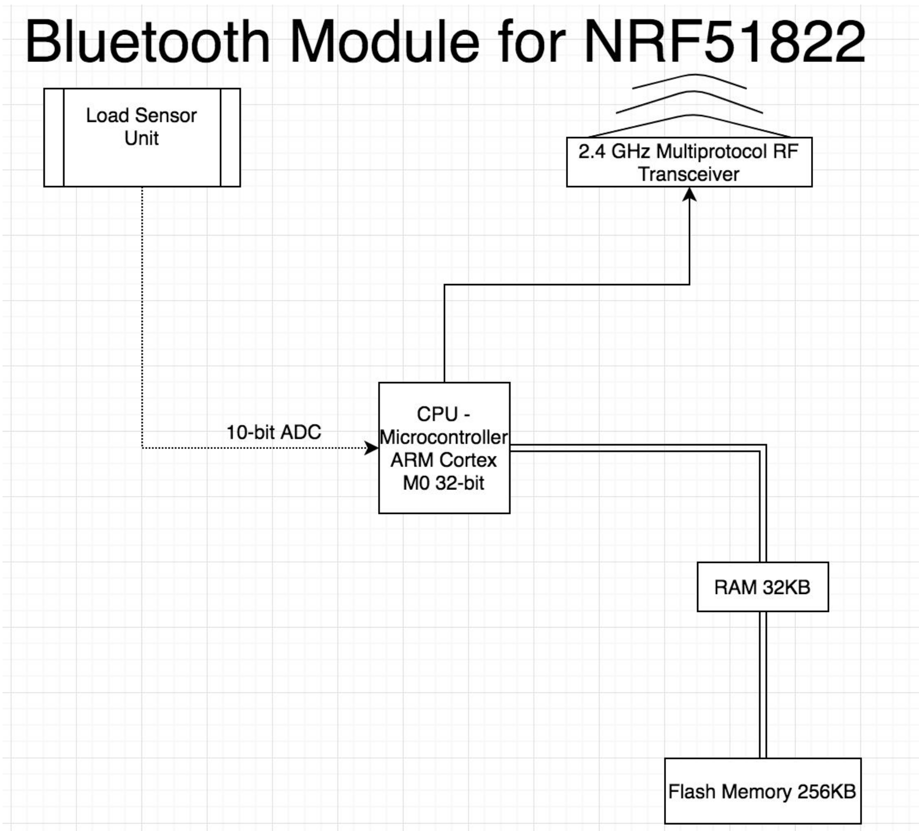

Figure 8 . Bluetooth Module

2.4 Power Module

A power supply will be used to power the components of the coaster while the coaster is in use.

2.4.1 Lithium Coin Cell Battery

The lithium ion battery will be the size of a coin and be able to power the load sensor, microcontroller and communication antenna. The battery does not need to power it continuously since our coaster should only be used for around 2 and a half hours at maximum.

Requirements	Verifications
1. The coin cell battery should provide between 2.7-3.3 Volts with	1. Using a multimeter, measure the voltage across the battery and confirm it is within the specified range

2.4.2 Power Switch

A power switch will control the circuit and determine whether the coin cell battery will power the rest of the circuit and allow us to control when the coaster is on.

The button needs a debouncing circuit. A simple mechanical switch will not function for this since the inputs are not always as we want them to be and can bounce between 0 and 1 for a moment. A debouncer circuit is a better alternative because the previous values of the circuit are held when A and B are kept at high, allowing for the removal of a momentary incorrect input.

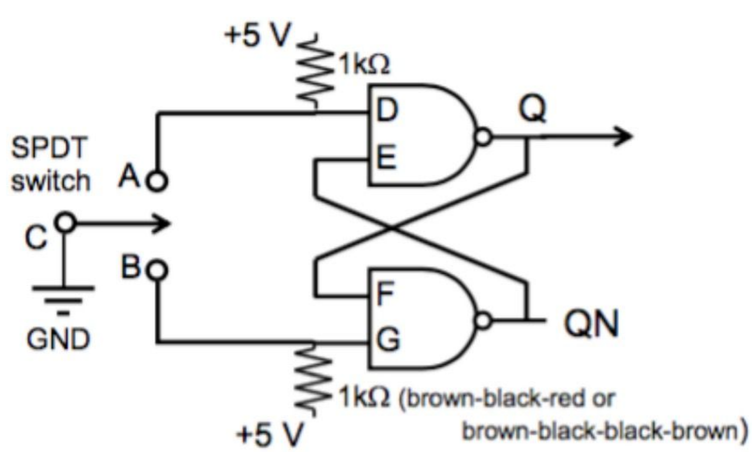

Figure 9 . Debouncing Circuit

Requirements	Verifications
1. Button should be easily pressible	1. Press button and confirm that can be easily pressed without strain

2.4.3 Step Up Voltage Regulator (5V)

A boost converter circuit will be used to convert the battery voltage to 5 Volts. This will be placed along the circuit to allow us to have a 5 Volt line to power the sensor circuit.

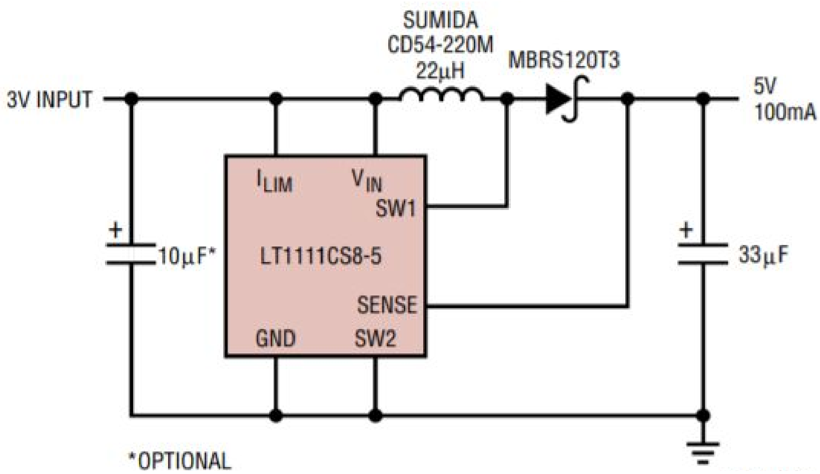

Figure 10 . Boost Converting Circuit

Requirements	Verifications
1. Boost Converting circuit should output a voltage in the range of 4.7 to 5.3 Volts	1. Using a multimeter, measure the output voltage and confirm it is within specified range

2.4.4 Inverting Voltage Regulator (-1V)

An inverting op amp will be used to convert the 3 Volts down to -1 Volt to be used with the sensor to determine the range of weights we want to track for the sensor. This voltage line will be connected to the negative lead of the sensor to determine the weight range output. Based on the data sheet, providing the sensor with -1 V will put the sensor in a range of 0.2 to 25 lbs.

$$\frac{Vout}{Voin} = \frac{-1}{3} = \frac{R2}{R1} = \frac{10K\Omega}{30K\Omega}$$

Requirements	Verifications
1. Inverting circuit should output a voltage	1. Using a multimeter, measure the output

in the range of -0.7 to -1.3 Volts	voltage and confirm it is within the specified range

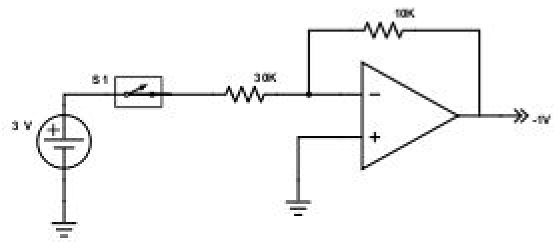

Figure 11 . Inverting Voltage Circuit

2.5 Hub

The Central Hub will be responsible for doing all the signal processing of the transmitted weights. The server will input the bare weight of the cup into the number pad for the corresponding coaster so that the microcontroller can use that weight to determine the amount of liquid is in the cup. If the liquid reaches a certain threshold, and LED corresponding to the coaster will turn on indicating to the server that the persons drink is empty or almost empty. The button is an immediate reset to turn of the LED so the waiter can indicate that this person has been helped.

2.5.1 Number Pad

A number pad will be used to set the weight of the bare cup without any liquids for each coaster. This number pad allows us to make our coasters more versatile and understand data yielded from cups of any weight.

Requirements	Verifications
1. The number pad should allow you to press a button and the resulting number should be sent to the microcontroller	1. Connect microcontroller to terminal via UART and the digit of the button pressed should be displayed on the terminal

2.5.2 LED Display and Button

This LED Display will be used to provide a visual aid as to which cup on the table is empty. This is simply an additional aid provided. The button will be used to reset the LED to note that the customer has been served. Based on the frequency at which we transmit signals, the LED will naturally get reset within one minute, however, this button allows for an immediate reset.

Requirements	Verifications
1. LED should light up when corresponding coaster has less than 10% of the drink left 2. Button should turn off LED when pressed indicating customer has been served 3. If customer has been served before button pressed, and MCU receives new data indicating full cup, LED should turn off	1. Send signal to Bluetooth receiver imitating low drink on specific coaster and confirm that corresponding LED lights up 2. When LED is lit, press button and confirm that LED turns off 3. Send signal to Bluetooth receiver imitating low drink, and confirm that corresponding LED lights up, then send signal indicating full drink and confirm that LED turns off

2.5.3 Antenna

The antenna on the hub will receive signals from the coaster and then send it to the microcontroller for processing. The signal it should receive should be the average weight of the cup and drink at that moment. The antenna should always be receiving since there is no set time that the coaster will be transmitting.

Requirements	Verifications
1. Bluetooth receiver should be actively listening for a signal from the coaster and receiving it when it does come in	1. Program Bluetooth transmitter on coaster to broadcast and confirm that we receive the same signal on the receiver

2.5.4 Battery

The Central Hub will be powered by a 3.7 V battery. The size of this battery is not as big of a concern as the coin cell battery since the central hub is not limited in size. Ideally, the battery should be able to power the microcontroller and the bluetooth receiver.

Requirements	Verifications
1. The battery should provide between 3.4 and 4.0 Volts reliably	1. Measure voltage of battery with a multimeter to confirm that battery voltage is within the range specified

2.5.5 Microcontroller

The microcontroller in the hub is responsible for all signal processing. Users will input the bare weight of the cup for the specific coaster so that when it receives the signal from the bluetooth receiving antenna, it will be able to determine the weight of the drink in the specific cup. If the drink in the cup reaches a threshold amount, it will turn on the specific LED corresponding to that coaster. On top of that, it will also turn off the LED if the corresponding button is pressed or it receives a signal identifying that the cup is above the threshold weight again.

Requirements	Verifications
1. The microcontroller should be able to receive UART signals 2. The microcontroller should have 8 GPIO pins that can output signals to LEDS and receive a digital signal from buttons Each LED and button represents a specific coaster	1. a. Connect microcontroller to a USB UART bridge and then connect it to a terminal b. Send it a string of 50 characters and have it echo back the characters c. Confirm that received string matches sent string’ 2. Confirm that MCU can be programmed to control and LED and accept input from a button

2.5.6 Step Down Voltage Regulator

This voltage regulator converts the 5V coming from the battery to a 3.3 Voltage line that is necessary to power the bluetooth receiver.

Requirements	Verifications
1. The battery should provide between 2.9 and 3.6 Volts reliably	1. Use a multimeter to measure the voltage of the following power line is within the specified range

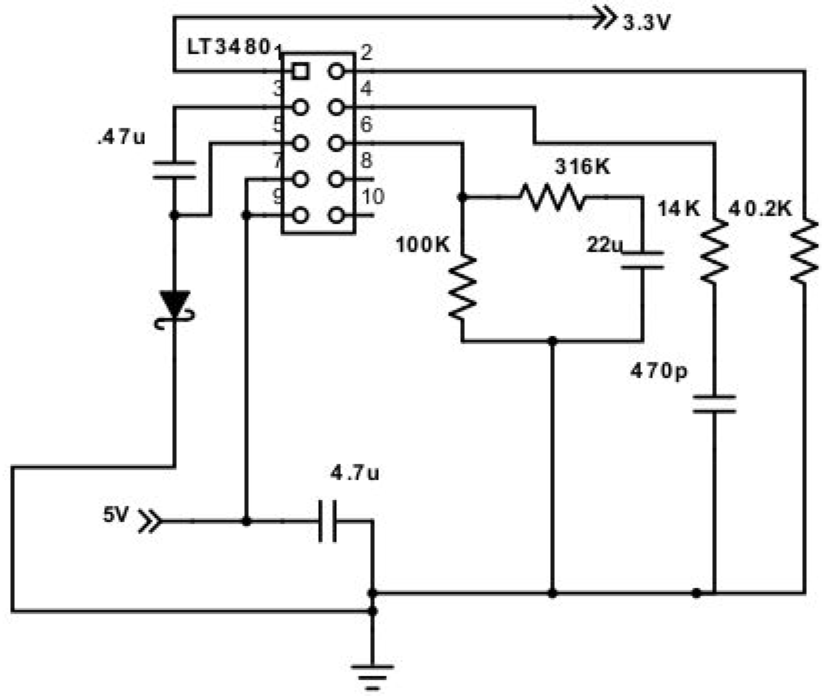

Figure 12 . Hub Power Circuit

2.5.7 Toggle Switch

A toggle switch will control the circuit and determine whether the battery will power the rest of the hub circuit and allow us to control when the coaster is on.

Requirements	Verifications
1. The switch should be easily switched on and off	1. Confirm that switch can be toggled with minimal effort

2.6 Server

2.6.1 Firebase

We need firebase to create an analytical platform where the data will be stored. This allows us to do many different activities and analytics on the data, making it quite versatile.

2.7 Schematics

2.7.1 Coaster Schematics

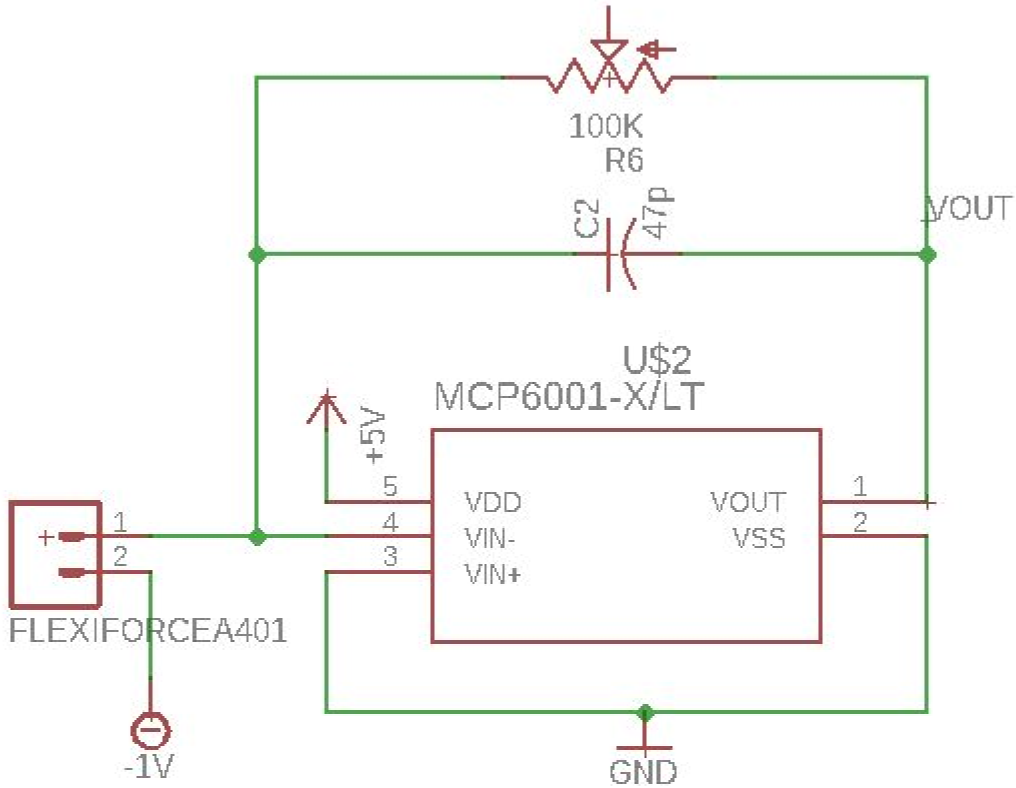

Figure 13. Sensor Circuit

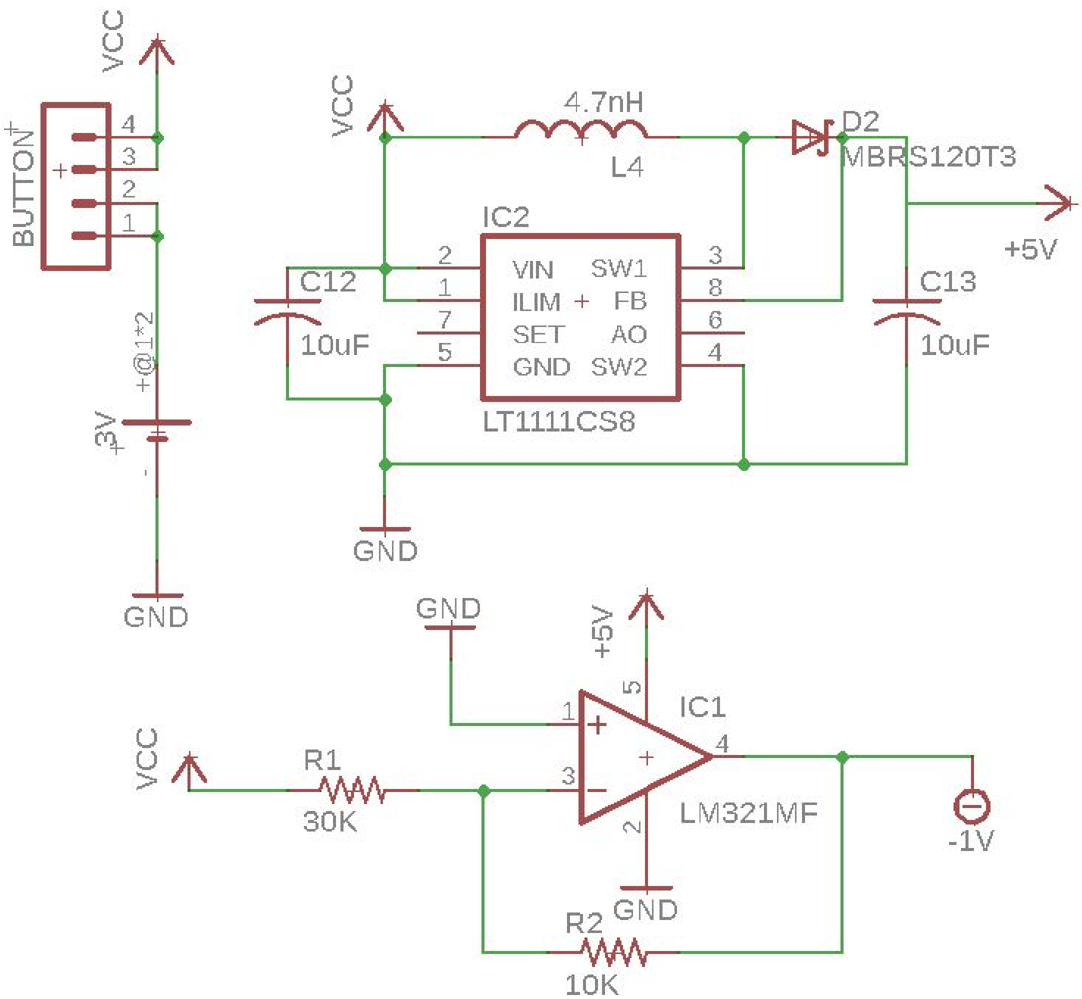

Figure 14 . Power Circuit

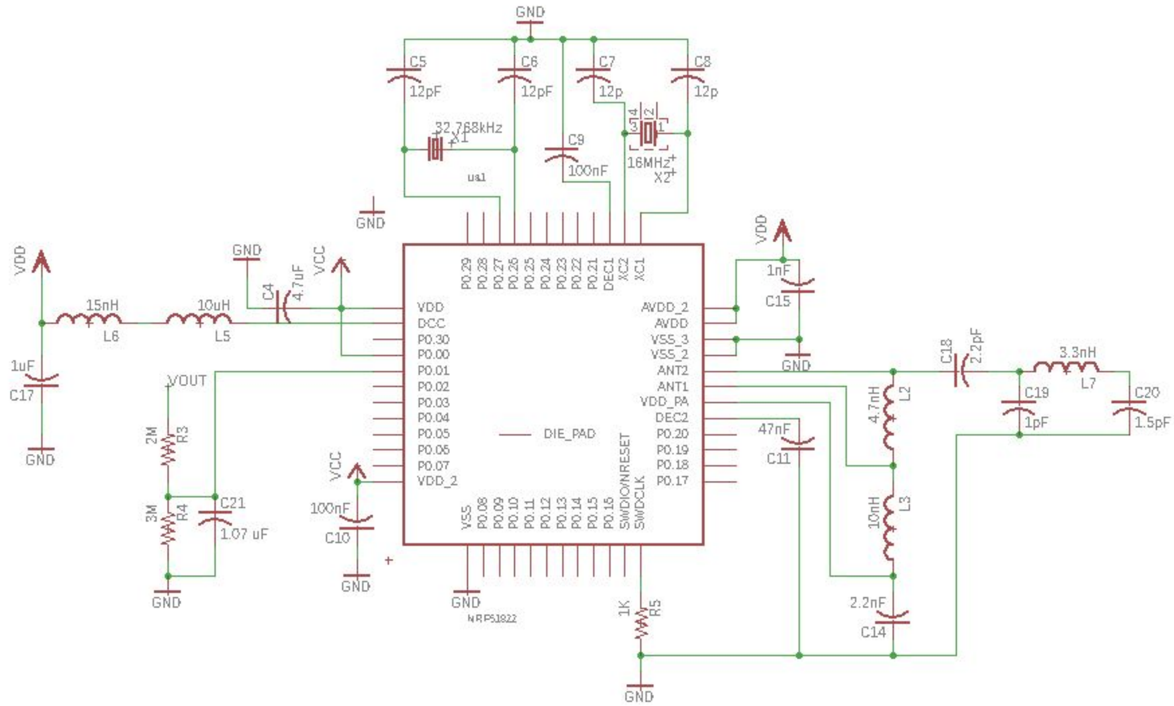

Figure 15 . Bluetooth Board and MCU

2.7.2 Hub Schematics

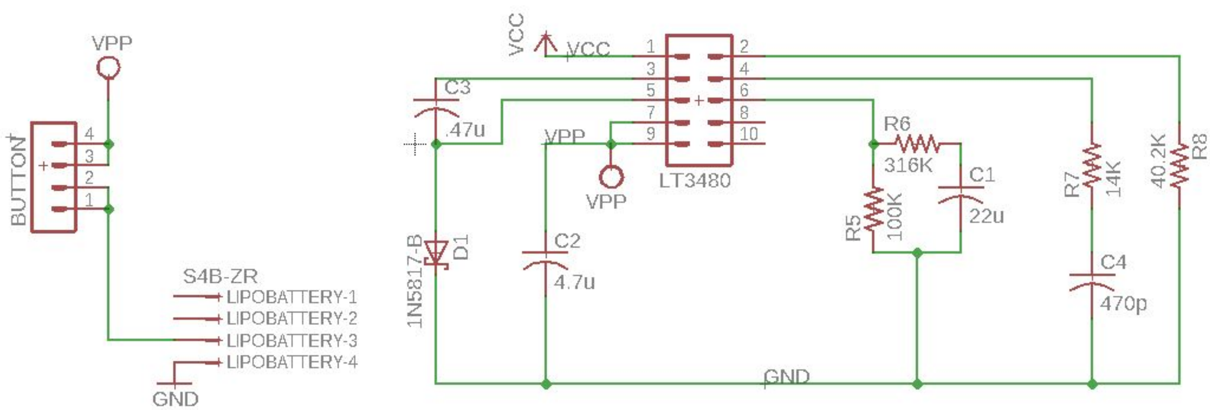

Figure 16 . Hub Power Circuit

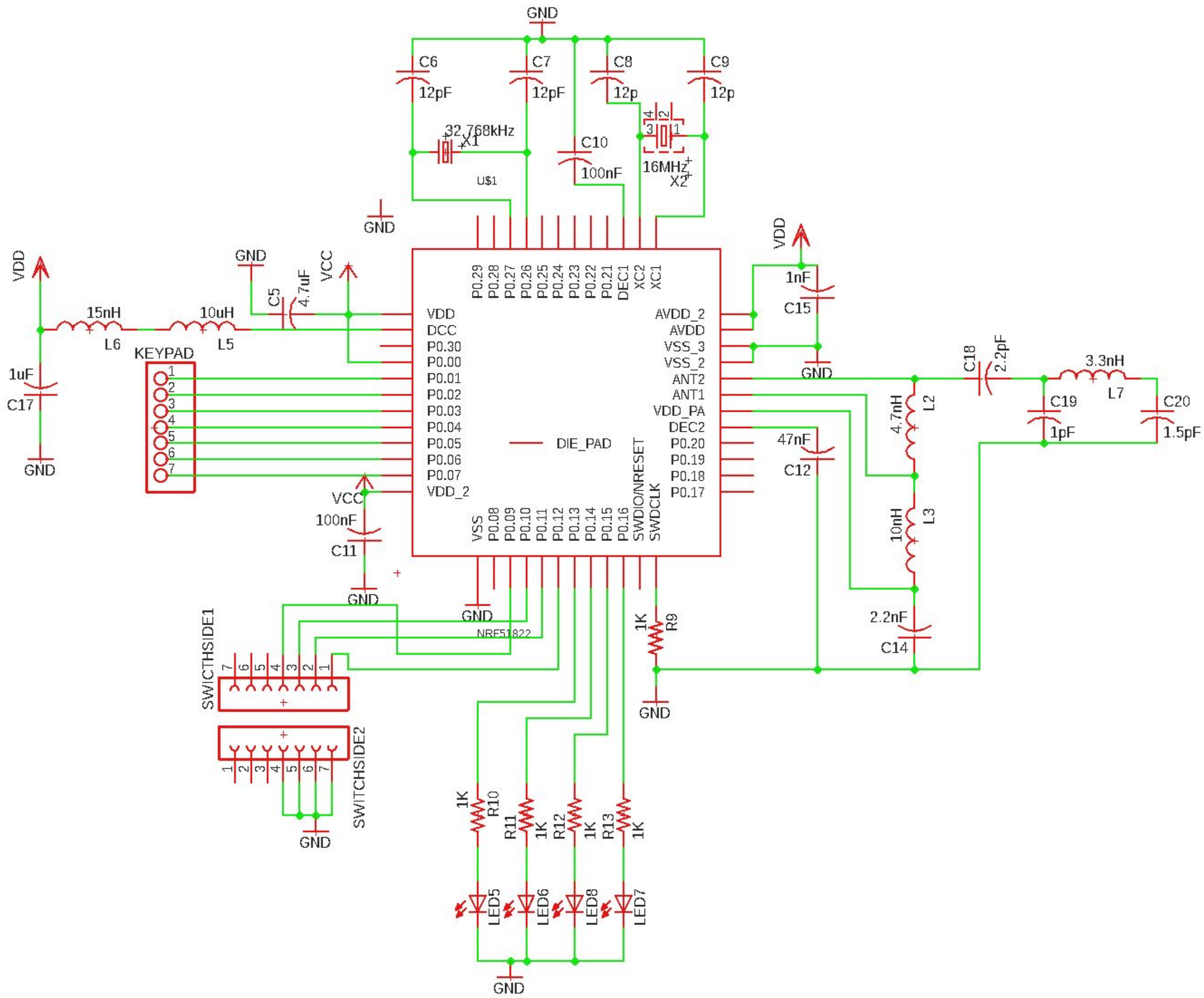

Figure 17 . Hub LED and Bluetooth Circuit with MCU

2.8 Risk Analysis

Getting the sensors to interface with our microcontroller while remaining inside the coaster will present a significant risk. Our sensor will most likely have leads that are connected onto a PCB using a Surface Mounted input port so that it can communicate with our microcontroller. Once, we can get a reading from our microcontroller using UART to the computer, we will work on connecting the communication module.

The most significant risk to the successful completion of this project is the communication module. We are faced with quite a few challenges in this regard and must consider many factors prior to determining what route to take. For now, we have resorted to going with a bluetooth communication module because of the lower current usage as compared to WiFi which will allow us to extend the lifetime of the coaster. We must ensure that this technology is capable of transmitting data within about 25 meters in various directions which becomes a significant challenge with Bluetooth. This is challenging to accomplish given that we must keep the size of the PCB and overall coaster relatively small.

Connecting the two modules with the power module should not be too difficult as the chosen microcontroller and bluetooth chip are both capable of being run off 3.3 Volts so we do not have to have multiple different power lines to power our different modules. The bigger issue comes rather from the current draw. The bluetooth SOC has a peak current draw of 6 mA when it is transmitting and 9 mA when it is receiving so that may be strenuous for the battery but given that we plan on transmitting once a minute, the SOC should be idle which reduces current draw to 1-2 uA.

2.9 Software

The software is imperative in offering instructions on the microcontroller to send the data received from the load sensor and formatting it to a packet that is sent via bluetooth IC antenna at 2.4Ghz frequency. The software development will revolve around programming the microcontroller to send out the packet every minute with averaged sensor data that will be computed and stored in the control unit.

Transportation Protocol:

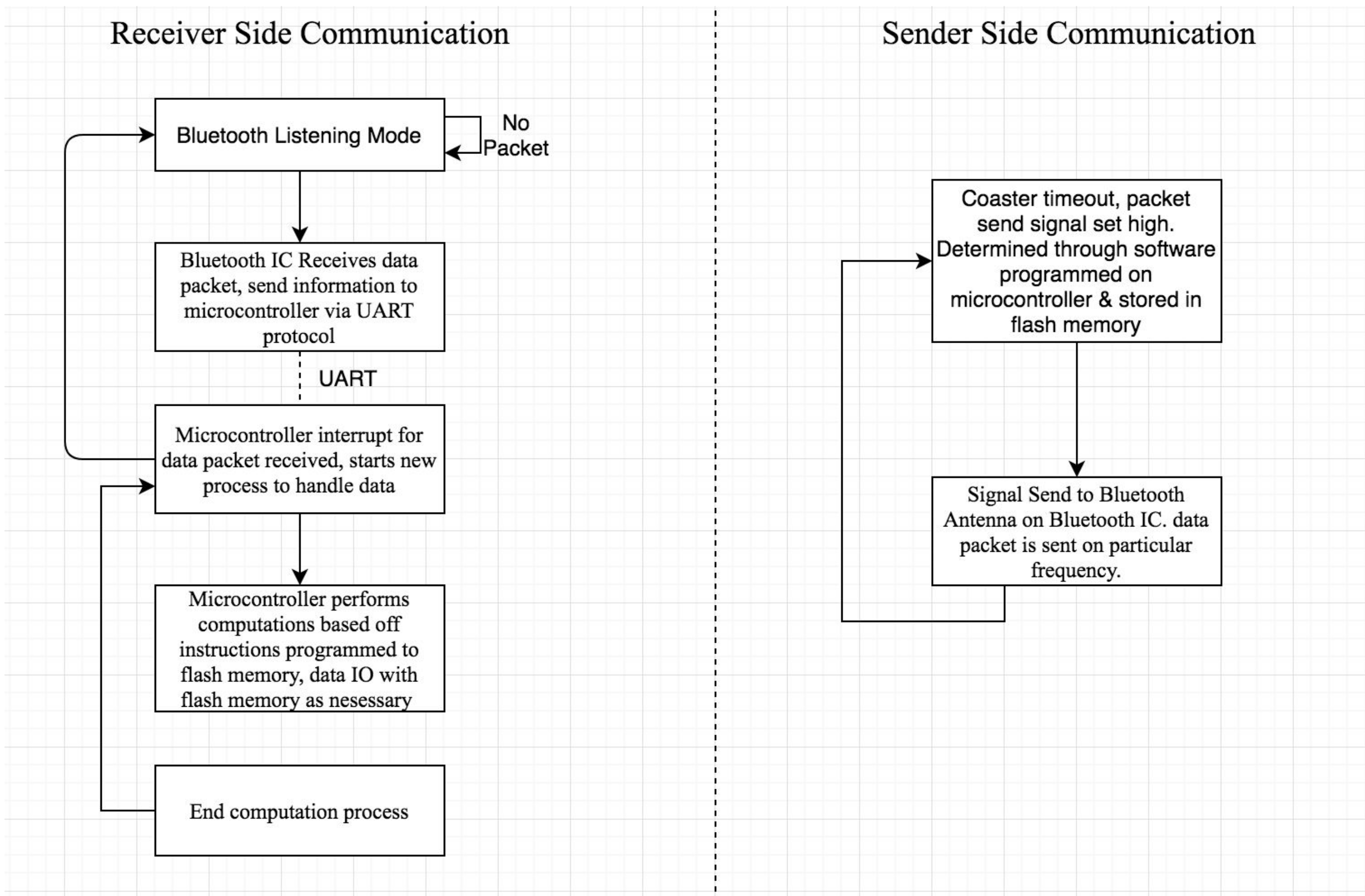

Figure 18 . Communication Algorithm

2.10 Tolerance Analysis

Our project is a tool used by waiters and waitresses to determine who has finished their drink or is almost done with their drink and provide faster service. Our coaster will track the weight of the cup and its drink and then send the data to a central hub which the server can use to determine who needs service.

The basis of our project is measuring the weight of the cup and its drink so it is important for the sensor to operate as expected. The sensor chosen should measure the weight of the drink and the cup within a 5-10% tolerance and should respond fast enough so that we can send an average weight after a minute that can account for random spikes from placing the cup down or picking it up.

The load sensor circuit provides an analog voltage described by figure 6 which follows the following equation.

$$V_{out} = -V_T \frac{R_F}{R_S}$$

V_T represent the negative lead voltage and R_F is the feedback resistor while R_S is the resistance of the sensor. R_S is determined by the force applied to the sensor and has a maximum drift 5% on a logarithmic time scale whereas V_T is determined by our inverting voltage circuit.

In the circuit described in Figure 6, we supply our op amp with 5 Volts, and the final output voltage of the sensor circuit itself can also reach 5 V. This presents another area for concern because our microcontroller uses a 3 Volt power supply. Because of this, we should use a resistor divider circuit to guarantee that the voltage created by the sensor circuit can always be read by the analog pin of the microcontroller. On top of that, the measured resistor in the circuit is shunted with a capacitor to help filter out any spikes in the circuit.
Because we want our range to be from 0 to 3 Volts instead of 0 to 5 Volts, we plan to use a simple voltage divider circuit where we have a 2 MΩ resistor in parallel with a 3 MΩ resistor as shown in Figure 19. On top of that, we want to shunt the 3 MΩ resistor with a capacitor. Using the datasheet of the microcontroller, and these resistors, we determined the value of the capacitor to 1.07 μF through the following equations.

$$Vmax = 5,\ R1 = 2M\Omega,\ R3 = 3M\Omega,\ t = 68\mu s,\ V_{1b} = 1.17mV,\ V_{ain} = .6V$$

$$V_{ain-samp} = Vmax * \frac{R2||R_{ain}}{R2||R_{ain}+R1} + Vain * \frac{R1||R2}{R2||R1+R_{ain}} = .8341$$

$$V_{ain-not-samp} = Vmax * \frac{R2}{R1+R2} = 3$$

$$V_0 = V_{ain=not-samp} - V_{ain-samp} = 2.1659$$

$$C = \frac{-t}{(R1||R2||R_{ain})ln\left(\frac{V_0 - V_{1b}}{V_0}\right)} = 1.0752\ \mu F$$

The ain subscript refers to the analog input resistance and voltage

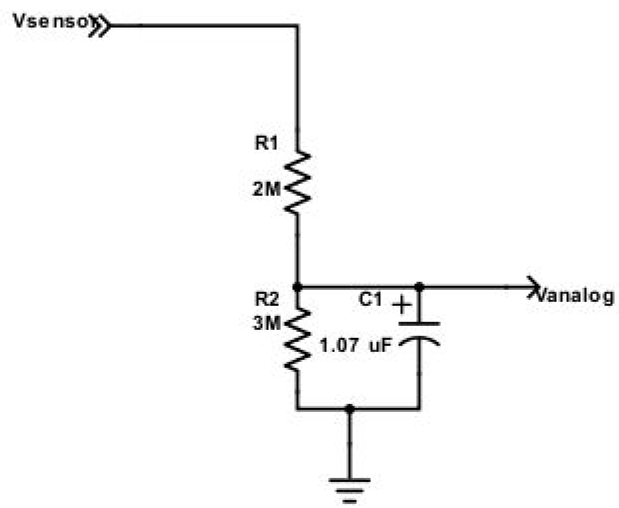

Figure 19 . Voltage Divider Circuit

The voltage source for the inverting circuit is the coin cell battery that should provide a nominal voltage of 3V. As time goes on, the battery discharges slightly depending on the load as shown in Figure 20. Because of this, the output of the inverting circuit will decrease in magnitude which would then decrease our output voltage and this change the range we are measuring in slightly.

Because of the drift in our sensor and the discharge of the battery, the range of weights we are measuring may change as well so the equation we determine from our characterization of the sensor may not accurately describe the current operation.

Looking at these three possible causes for getting an inaccurate measurement, the battery voltage seems like it would play the biggest factor in the final calculation of the weight.

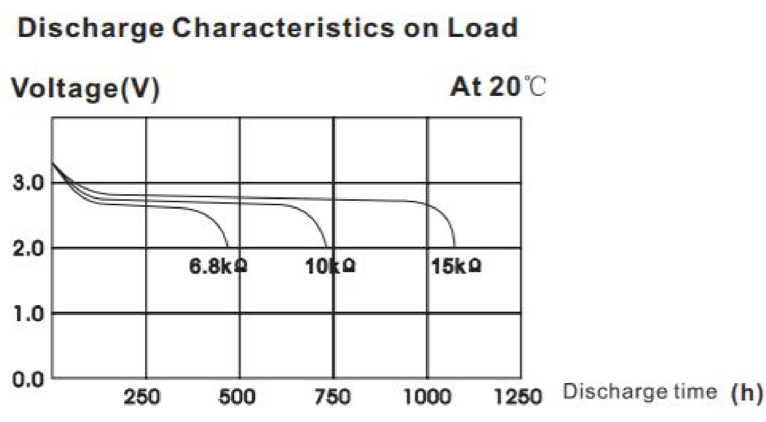

Figure 20. Discharge of the battery over time

3 Schedule & Costs

3.1 Schedule

Schedule			
Week	**Shray**	**Suraj**	**Shivam**
2/19/18	Finish Design Document & Order Parts from DD		
2/26/18	Design PCB/Characterize Sensor		
3/5/18	- Soldering Assignment - Testing power supply circuit	- Soldering Assignment - Research bluetooth protocols and transmission	
3/12/18	- Testing/Confirming load sensor characterization	- Testing bluetooth TX of coaster	
3/19/18	*Spring Break/Research*		
3/26/18	- Designing 3D printed coaster - Testing PCB - Redesign PCB if needed	- Testing bluetooth RX of hub - Testing PCB - Redesign PCB if needed	
4/2/18	- Integrate various independent modules		
4/9/18	- Integrate various independent modules		
4/16/18	- Testing final prototype - Bug fixes/debugging		
4/23/18	Final Paper and Presentation		
4/30/18	Final Paper and Presentation		

3.1 Costs

Part Costs:

Part	Cost	Quantity
Lithium Ion Cell-Battery	$1.95	2
LiPo Battery Pack	$9.95	1
Tactile Push Button Switch (20 pack)	$4.95	1
Weight Sensor (Flexiforce A401)	$24.95	2
PCB Hub	$3.10	1
PCB Coaster	$3.10	2
Bluetooth SOC (nRF51822)	$4.03	3
Op-Amps	$0.35	7
LEDS	$0.20	5
Buttons	$0.95	4
Number Pad	$3.95	1
Circuit Passives (Resistor, Capacitor, Inductors)	$10.00	
3D Printer Filament	$5	1
Total Cost	$116.29	

The previous cost outlined are under the assumption that we develop 2 coasters.

Labor Costs:

- Employee rated at $40/hour
- Each team member (3) expects to put in 10-15 hours a week
- Worked on this project for approximately 14 weeks

$$Total\ Labor\ Costs = 3 * \frac{\$40}{hour} * \frac{10\text{–}15\ hours}{week} * 14\ weeks = \$16,800 - \$25,200$$

4 Safety and Ethics

4.1.1 Hardware Safety

For this project, we will be using a lithium-based coin cell battery. In general, any energy storage device (battery), carries the risk of overheating or exploding. Cells with ultra-thin separators of 24µm or less are more susceptible to impurities, so we will make sure we don't use such batteries.[5]

A common issue with using lithium-ion batteries tends be thermal runaway. This occurs when microscopic metal particles converge to one spot and a short develops and a sizable current will flow between the positive and negative plates. The temperature rises; this is also referred to as 'venting with flame.' [5] In order to avoid this, we will closely monitor the temperature of the lithium-ion coin cell temperature and keep the cell away from sensitive technology. This also means that we should be very careful with our calculations and ensure that we don't have too much voltage going through, prior to attaching the battery.

Our goal with this product is to make this as versatile as possible. As a result, we aspire to create a product that functions with any beverage. Therefore, we must take into account the varying temperatures that this coaster may be exposed to. This poses a risk as there will be technological components such as batteries and sensors in close proximity with somewhat hot or cold temperatures. As a result, we need to ensure that the coaster is thick enough or is of some material that shields the battery and sensors from the potentially extreme temperature.

Similar to the previously raised concern, since this is a beverage coaster, there will be inevitable exposure to liquids. We must ensure that the components consisting of charge or electrical components are secluded and separated from any liquid exposure potential. This means that the coaster itself must have no leaks or gaps that expose the internal circuitry.

4.1.2 Network Security Safety

When using a number of connected devices, sometimes, with the large numbers of devices that have wireless communication capabilities, we run into danger of overloading the network causing it to fail to deliver data packet. If too many IOT/bluetooth devices try to send packets at the same time, the congestion could cause a buffer overload, if there even is a buffer. The reliability and functionality of the network would be broken, thus is a risk we need to hedge against.

4.2 Ethics

We, the members of group 61 in ECE 445, understand the impact that our project can have on the daily lives of many users. As a result, we understand that it is of utmost importance to follow the highest professional and ethical standards and commit to all ten of the IEEE Code of Ethics. [6]

More specifically, in the process of constructing this beverage coaster, we must take into account #1 and #9 of the code of ethics. We must hold the safety, health and welfare of the public paramount. We will be dealing with beverages that will be consumed by our consumer. As a result, we must not actually alter the beverage in any way. Our product is to simply take readings on the pressure applied by the drink, and we must stop at that. #9 also falls under a similar situation. We must avoid injuring others, their property, reputation, or employment by false or malicious action. The same applies of not altering the actual liquid that is being consumed.

We must also take into consideration #3 on the code of ethics. We must be honest and realistic in stating claims or estimates based on available data. Various services such as restaurants will be relying on our system to know when to serve/refill beverages. We must ensure that these readings are accurate, as advertised. Throughout the building of this project, we must also take into account #7 of the code of ethics. We must seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contribution of others. We must take into account all that our TA and course staff suggest and put significant consideration into those pieces of advice.

5 References

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