Liquid Detection Cup

Team 72 -

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1. INTRODUCTION

1.1 Problem and Solution Overview.

The objective of our system is to be able to detect that a cup is running low on water, and convey this information to a nearby server. Places such as Red Robin offer free refills on their bottomless drinks [1], meaning multiple different cups are necessary for multiple different drinks. Red Robin's current solution is to flag down a waiter and tell them what to refill it with so that the waiter can comply.

The previous solution was to use weight sensors in the coasters underneath cups. While weight sensors function fine as a detection system, they can not differentiate between different cups placed on top of them. Furthermore, a cup that only contains ice may still have enough weight to prevent the sensor from triggering. As such, we have decided to place a sensor directly into the cup to solve both problems.

Our solution is to implement a sensor directly onto the cup which will detect the water level of the cup. When the water threshold falls below 25%, a multicolor LED will light up to tell the waiter of the specific location of the cup, and a message will be sent directly to the serving station so an idle waiter can immediately fill their cup.

1.2 Visual Aid

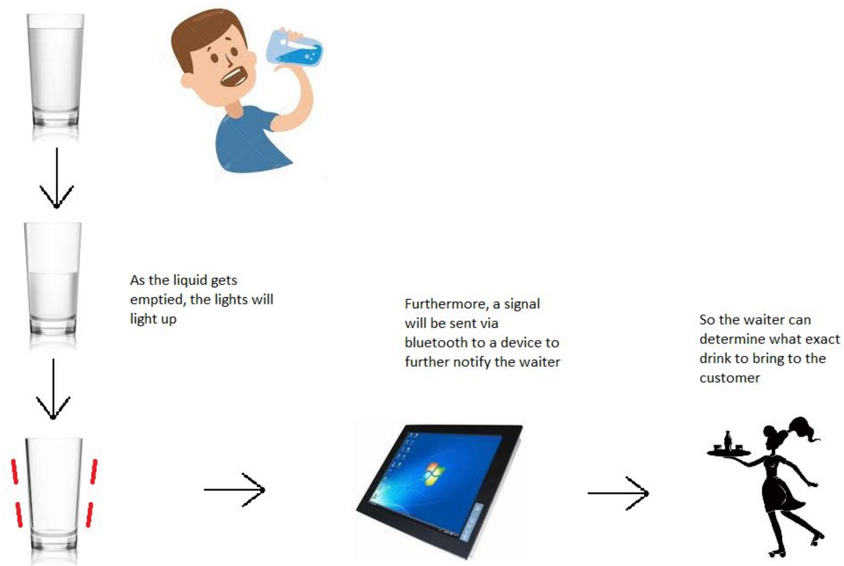

Fig.1 High-Level Schematic

1.3 High-level requirements list

1.3.1. Accuracy

The system needs to be able to respond to a cup running low on water with a 99% accuracy rate, without incurring more than a 5% false alarm rate, such as when a person is actively drinking from the water or swishing it around.

1.3.2. Size & weight.

The system band on the cup will not be thicker than 5mm. The system's weight also will have to be smaller than 15% of the full glass. This requirement is for the customer comfortness.

1.3.3. Longevity

The battery life should be at least 45 minutes before the coin cell batteries need replacing. The average current in 1 year must be 200uA.

2. DESIGN

2.1 Block Diagram

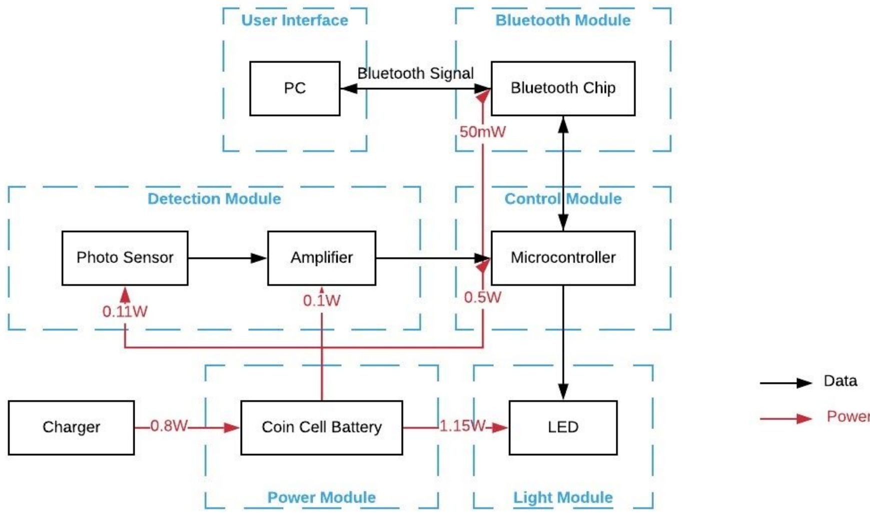

Fig.2 Block Diagram

2.2 Physical Design

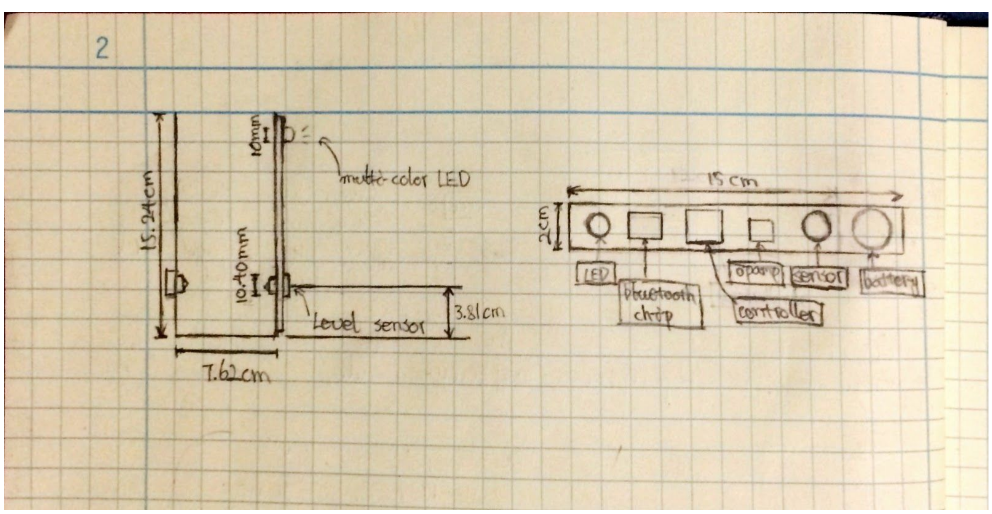

Fig.3 Physical Setup (a)

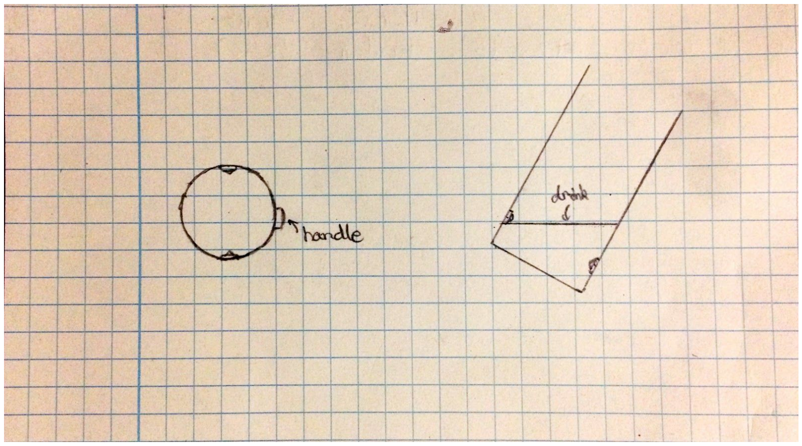

Fig.4 Physical Setup (b)

To mitigate the effects of the cup's tilting on the accuracy of detection, two sensors are embedded on opposite sides of the cup. When the user grabs the handle to drink, it's likely that one sensor is submerged and the other is not, even when the drink level is not below 25%. To account for that, the control module receives signals from both sensors, and it sends an alarm only when both sensors are not submerged.

2.3. Detection Module

The detection module is required to accurately detect the distance between the surface level of the drink, and amplify the signal to a 2.0 V signal to send to the control module. The sensor will consist of an infrared LED and a phototransistor, embedded in a sensing tip. When the sensor is in the air, the IR signal bounces inside the tip and comes back to the transistor because of the refractive index difference between the plastic cone and the air, and a strong signal is received. When in a liquid, however, the IR light comes out a lot into the liquid, and the received signal is smaller. Since the sensor utilizes IR light, it's not affected by the lighting conditions of the environment. The sensors are embedded near the bottom of the cup to account for when the drink is emptied. This kind of sensing system is used for its smaller size than a capacitive sensor, which involves a capacitor tube sticking into the liquid, taking up much space. But it has disadvantages, in that when a "thick" liquid with reflective large particles, such as milk, is being detected, the signal may be misread. A double sensor system is embedded to mitigate the error introduced by random tilts to an approximate level of 4%.

Since the sensors are directly in contact with the drink, detailed experiments will need to be set up to verify its functionality under different conditions, for example in drinks with particles of different sizes; other factors, like the temperature of the drink and its waterproof ability, are also essential and need verifying.

Requirement	Verification
OLS200D3SH Photo Sensor 1. Have a logical on/off output at 1.0V/0.5V +- 0.05V. 2. Function properly under 4.5V+-10%, 25mA+-4% input. 3. Function properly in a liquid environment. 4. Function properly in drinks with particles of different sizes with a 4% tolerance. For verification, prepare water, beer and milk. 5. Function properly under a varying temperature of 4-60 degrees Celsius with a 4% tolerance. For verification, prepare water at temperatures 4, 20, 40, 60 degrees Celsius.	1. Test sensor under different environments, observe desired output. 2. Connect sensor to specified input to verify working condition for at least 3 hours. 3. (a) Place sensor in water. (b) Constantly monitor the outputs for at least 3 hours to verify its waterproof ability. 4. (a) Verify the sensor is working properly when exposed in the air. (b) Put the sensor in the water; monitor and record the output data. (c) Repeat steps (a) and (b) for beer and milk. (d) Compare data from the three cases to verify that output differences are within acceptable levels. 5. (a) Verify the sensor is working properly when exposed in the air. (b) Put the sensor in the water at 4 degrees Celsius for 1 minute; monitor and record the output data. (c) Repeat steps (a) and (b) for the water at 20, 40, and 60 degrees Celsius. (d) Compare data from the four cases to verify that output differences across the four cases, and in each case across the 1 minute interval, are within acceptable levels.
Amplifier 1. Have a 2x gain. 2. Introduces less than 3dB noise.	1. Input a varying 1.0V level signal, and observe the output to be 2.0V level. 2. Run an oscilloscope check to verify a desirable SNR.

2.4 Control Module

In this case, we had two design options: make the control module calculate if the cup is empty or not and then directly send the data to the computer via the bluetooth module or send the data the sensors had previously detected of how much liquid is in the cup.

- In the first case, computation of calculating whether the glass is full will be done in the control module, so therefore in the microchip, in order to do that the microchip will have to be powerful enough to do all the calculations part. In addition, with this option we will make the Bluetooth module have less workload, as the bluetooth module transmission is the part of the whole that will use the most energy and if we use it more, then we will use more energy of the batteries. Moreover, this approach is more scalable and will avoid bottleneck problems and single failure. A negative part of this option is that, as the microchip has to be more powerful, it will considerably increase the cost of the project, as the price of the microchip will increase and the price is multiplied by the number of glasses (each glass will have a microchip integrated).
- In the second case, the control part will be less loaded and as a result we can have a simpler microchip. Calculations will be done in the computer, that will be much more powerful than any microchip on the market. As the computation part will be done in the computer, we can get faster computation results and results will be more accurate, which for our case will be more important.

Taking into account and having developed both options, we will use the first approach, as it has more benefits and more importantly speaking of energy saving it will be better, taking into account the following data:

Radio Transmit average current cost: 12 mA.

CPU Active: 4.6 mA.

With this option, we will have to be aware of the calculation speed of the microchip and how powerful it will need to be. We will also have to make the program as efficient and fast as possible so it will help the microchip.

The control part will need to have an analog to digital converter as the input signal from the detection module will be analog and the output signal to the bluetooth module must be digital.

The requirement and verification table for this part will be:

Requirement	Verification
Program execution time 1. Execution time must be smaller than 30 ms from the glass being emptied until it is sent to the Bluetooth module. 2. Clock speed will have to be greater than 4Mhz.	a. Use a variable that will count the time it takes to execute. b. Verify the latency is within the acceptable level.
Analog to digital Converter. 1. The controller will have to have an analog to digital converter integrated. 2. Process signals at 2.0V level to 10-bit digital output.	a. Send a signal with varying amplitude in the 0-2.0V range and varying frequency of 50-5K Hz. b. Will have the ability to detect 1024 discrete analog levels. c. Verify a conforming digital output to the original signal's shape.

2.5 Bluetooth Module

The bluetooth chip is required to send and receive the wireless signals from the control and user interface modules. In order to accomplish this, we will use an UART data transmitter, but we will need a small one, because we do not want it to be very big as it will have to be part of the glass and the one drinking from will not be uncomfortable when drinking.

Requirement	Verification
Size. 1. Dimensions cannot be larger than 12 mm x 22 mm.	a. Using a milimetric rule and checking if it is not very large.

Latency. 2. Sends data with less than 200 ms..	a. Send a command from the control module. b. Verify the Bluetooth module's reception. c. Computer receives the command with acceptable latency.
Time. 2. Data rate should be at least 10 kbps.	a. Send a command from the control module forcing the data rate more than 10 kbps. b. Verify the Bluetooth module's reception is correct.
Humidity allowance. 3. Operating Relative Humidity Range 40% to 90% 4. Storage Relative Humidity Range 40% to 90%.	a. Putting the bluetooth module next to a humid place in conditions similar to being next to a cup of liquid. b. Send a command from the control module. c. Verify the Bluetooth module' reception is correct.
Low operating voltage. 5. Supply operating voltage 1.9 V to 3.6 V.	a. Connecting the Bluetooth module to a voltage supply source in the operating voltage. b. Send a command from the control module. c. Verify the Bluetooth module's reception is correct.
Low current consumption. 6. Average current consumption in advertising mode cannot be more than 1.061 mA transmitting in intervals of 20 ms. 7. Average current consumption in connected mode cannot be more than 2.10 in intervals of 100 ms.	a. Connecting the Bluetooth module to a low current source. b. Send a command from the control module. c. Verify the Bluetooth module's reception is correct.

2.6 Light Module

The LED is required to be able to display at least 4 distinct colors, and have a noticeable brightness level of at least 300mcd.

Requirement	Verification
Working Condition 1. Each input pin works at a 1.8-3.3V, 20mA+-5% input.	a. Provide the three input pins with the desired working input. b. Observe steady performance for at least 3 hours.
Variety in Colors 1. Able to emit 4 different color lights.	a. Drive current in the three input pins corresponding to RGB color. b. Observe red, green and blue colors, and drive red and green to show yellow.
Brightness 2. Emits lights at 300mcd +- 5%.	a. During verification of (2), verify brightness with a light meter.

2.7 User Interface

The system's user interface will be a laptop app that wirelessly communicates with the control modules to manage all the cups, allowing the user to modify the color of the LED associated with a specific cup before serving, and to receive the alarm signal sent by the control module in a real-time manner to provide a first hand reminder to the user, who will then look for the cup with the warning LED lit.

Requirement	Verification
Latency 1. Receives and sends signals within 500ms.	a. Run a simulation with the sensor to time and verify the latency is within acceptable levels.
Alarming 2. When signaling about a cup's empty, the user needs to realize it within 2 seconds.	a. During process (1), verify that the warning signal is easily seen within the required time by the user.
Concise	a. Run a simulation with 2, 5, and 10

3. When managing multiple cups, it needs to make a straightforward, concise list, which shows each individual cup's status.	sets of systems to verify that a manageable interface list is shown on the app.

2.8 Power Module

The Power Module needs to be able to power the Detection, Control, Bluetooth, and Light Module. This will need to provide power for at least 4 hours so that the system can stay on during a large portion of a working day. We will be using a coin cell battery for our Power Module, which is required to provide a 3V, 340mA.

Requirement	Verification
Coin Cell Battery 1. Main: Provides steady output of 3V +- 3%, 340mA+- 2% for at least 4 hours without charging.	1. (a) Connect battery to circuit. (b) Test to verify a stable 3 V, 340 mA output within tolerance for 4 hours.
Battery Charger 1. Steady charging output of 3.6V +- 5% and 500mA +- 3%. 2. Stable working temperature below 100degrees Celsius.	1. (a) Discharge battery. (b) Connect to the charger with an input of 7V. (c) Verify the charging voltage, current levels are within the designated levels. 2. (a) During charging, use a thermometer to measure and verify the charger's temperature.

2.9 Schematic

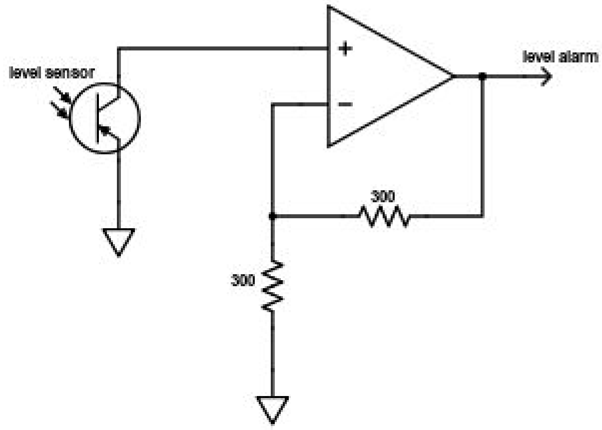

Fig.5 Detection Module Schematic

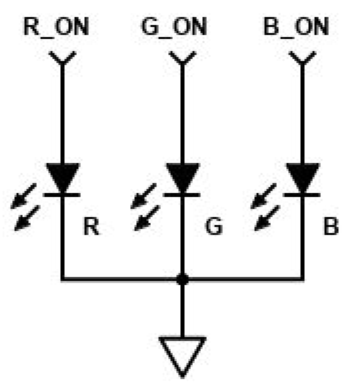

Fig.6 Light Module Schematic

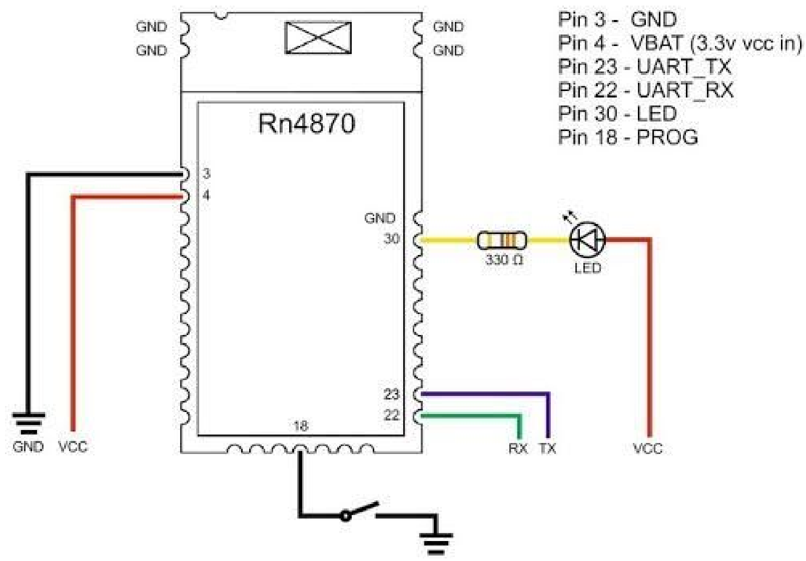

Fig.7 Simple Bluetooth Module Schematic

3.PROJECT DIFFERENCES.

3.1 Overview

The previous project used a weight sensor within the coaster to detect when drinks run low. They use a load sensor to detect the amount of beer in a glass while the beer is sitting on a coaster, as well as LED lights placed on the coaster to signal to a server when a beverage needs to be refilled. This data is also sent to a computer system, which in their case is an iPad, which records the beer consumption rate and also sends the information to the waiter.

Our project intends to place the entire system as an add on to standard cups instead of the coasters. By moving the system to the cups, we can also switch from load sensors to optical sensors. Outside of this key difference, we follow the original project pretty similarly. We send any information from our system to a computer at a serving station, which is a computer system in our case, which will record the consumption rate and notify any waiters.

Our change allows the cup to effectively ignore any solids in the cup that impact its weight, such as bubble tea, or ice cubes. Furthermore, different liquids have different densities, which may lead to incorrect readings from a sensor, as a drink like grenadine is ~18% more dense than water and vodka is ~8.5% less dense than water. Because of this, we can use these cups and differentiate the drinks via color coding in the LEDs while still using the same sensor regardless of drink.

The trade-offs is that we must place our system directly onto the cup, which represents a new host of challenges. For one, we must make our system completely waterproof and be more durable, as it will be in contact with liquids constantly, used by humans regularly, and cleaned much more thoroughly than a coaster. An optical sensor will also provide different problems compared to a load sensor, as it may not be able to detect milk as well, which reflects light effectively.

3.2 Analysis

The main purpose of our change is to make our system usable across a variety of different liquids regardless of density or objects inside of them. So we need to prove two things: that an optical sensor would achieve comparable functionality with the previous sensor and that a load sensor would provide inaccurate results for different drinks.

A study shows that, in Figure 6 [2], drinks of various concentration levels. The measurements are relative to water, which are known to be detectable using a standard optical sensor. Because the measured light intensity only increases in this test case, the optical sensor will be able to notice a clear difference between air and beer. Furthermore, the refractive index of ethanol is anywhere between 1.3 and 1.7, similar to the refractive index of water's 1.33 and far larger than the refractive index of air, which is 1. Because the optical sensor measures the difference in refractive index between the liquid and air, this is a clear indication that it can comfortably detect the presence of beer.

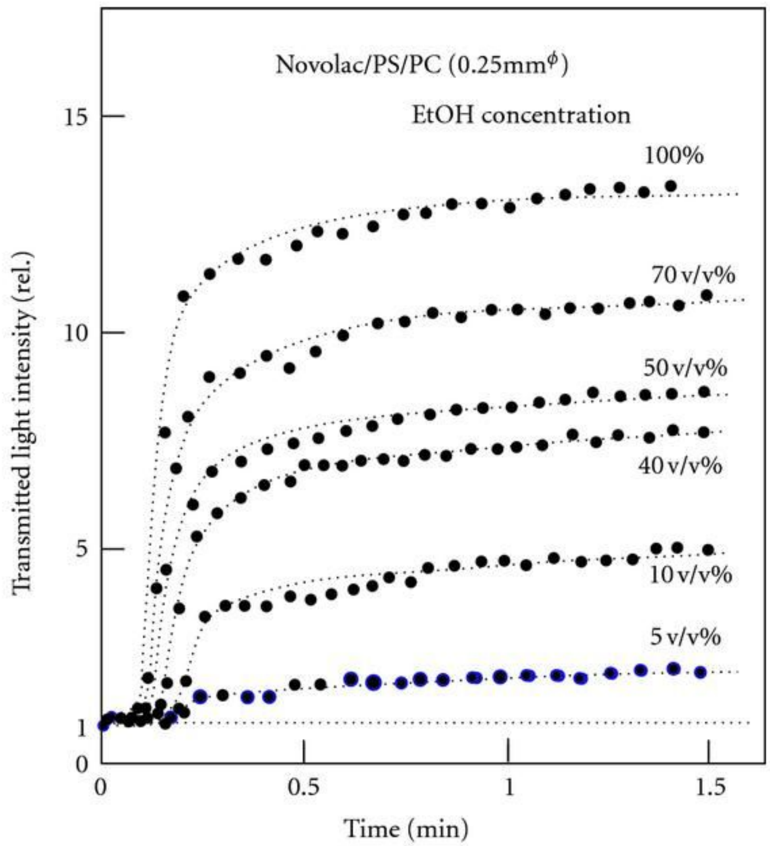

Fig.8 Light Intensity Due to Ethanol Concentration (relative to water)

Now we prove that there is an issue with detecting different liquids using a load sensor. A standard cup stores up to 20 ounces of water and also weighs 20 ounces. The implemented load sensor wanted a 5% granularity with water, or a sensor which can detect a granularity of 1 ounce. at 25% of the weight, which is when the cup would notify a need for a refill, the weight would have a threshold of 20+5 = about 25 ounces. However, Grenadine, which is 1.2 g/mL, would be about 26 ounces while pure ethanol, which is less than 0.8 g/mL, would be about 24 ounces. In both cases, the weight would be 5% lower or 5% higher, or one level different from its real value. Furthermore, if the cup was entirely full, the weight of Grenadine with the cup would come out to be 44 ounces, while ethanol would 36 ounces inside the cup. This means that the load sensor would detect that the cup was 120% and 80% full respectively.

These measurements also ignore weight values created by solids floating in the liquid, such as ice cubes. On average, ice is put into a cup at a 1:1 ratio with beer [3], which means a cup will have 50% ice in it. Ice has an average density of 0.92, meaning that if all the beer is drained but half of the ice is still in the cup, then the weight of the cup will be 24.6 ounces, which would barely trigger the 25% threshold. If there was 1 ounce of a liquid, even if that means the customer is almost out of his beer, our system would not output any information to a waiter using a load sensor. As such, an optical sensor will be able to more accurately determine the amount of liquid in a cup than a load sensor, and can also function just as well when looking at a glass of beer in a vacuum.

4.COST AND SCHEDULE.

4.1 Cost Analysis.

4.1.1 Labor.

We estimate that our fixed development costs are $40/hour and 10 hours/week for 3 people, done over 16 weeks:

$$3 * \frac{\$40}{hour} * \frac{10\ hours}{week} * 16\ weeks\ *\ 2.5\ = \$48,000$$

4.1.2 Parts.

Item	Price
Bluetooth transmitter (RN4871-I/RM130).	$7
Microchip controller (ATPMEGA328P-AU QFP).	$2
OLS200D3SH Level Sensor	$40.67
LM741 operational amplifier chip	$0.87
ERJ-8ENF3000V chip resistor	$0.20
ML-614S/FN manganese lithium coin battery	$1.96
1528-1944-ND coin cell charger	$14.95
COM-11120 RGB colored LED	$1.05

4.1.3 Sum.

48000+7+2+40.67+0.87+0.2+1.96+14.95+1.05 = $48068.70 For development costs. Afterwards, each one costs 68 dollars per unit.

4.2 Schedule.

Week #	Francis	Ran	Alfredo
1	Order Parts for Detection, Light, Power Module	Begin PCB design	Order parts for Bluetooth, Microcontroller
2	Order more parts as needed	Finish and submit PCB design	Begin work on Bluetooth Module
3	Begin construction of waterproof bands	Test Detection Module	Finish work on Bluetooth Module
4	Finish Construction	Test Light, Power Module	Test and bugfix Bluetooth Module
5	Put Light into prototype	Solder PCB components	Solder PCB components
6	Put Power Module and Detection Module into prototype	Test Microcontroller - Detection Module functionality	Test Microcontroller - Bluetooth
7	Test water Resistance	Put PCB into band	Test Microcontroller - Light Module functionality
8	Mock Demo/Finalizing	Mock Demo/Finalizing	Mock Demo/Finalizing
9	Demo	Demo	Demo
10	Prepare final presentation	Prepare final presentation	Prepare final report

5. ETHICS AND SAFETY

The general goal of both the IEEE Code of Ethics [4] and the ACM Code of Ethics [5] is to ensure quality without either intentionally or unintentionally causing harm. Our design does not appear to break any laws; the device's only detection module is a capacitive sensor, which will not invade anyone's privacy since it is only detecting capacitance to determine the water level. Furthermore, the sensor requires very little power and would not be harmful to a person.

The only wireless connections are made via bluetooth, so there is little to no possibility of invading personal privacy or interfering with other signals.

Every subsystem aside is contained within one compartment, which only comes in contact with the cup, a human intending to drink with it, and a liquid. We will take our due diligence to ensure that the device will be able to withstand hot conditions such as hot coffee. We also need to ensure that every module that requires power is encased in plastic to ensure that it will not harm any human contacting it. This will double as protection from water during either a wash or usage. Overall, the power required of the system is minimal, so risk is also at a minimum, and coin cell batteries are generally safe to use aside from swallowing concerns.

Water safety laws by the EPA[6] limits many chemicals and materials from being inside drinking water, as they create hazards. One notable material that is limited is copper, which will cause gastrointestinal distress and eventually liver and kidney damage. However, our priority is to ensure that our product will be encased in a waterproof layer that will both prevent any electronics from entering the drinking water and the drinking water from ruining our product. Because all metals and inorganic materials will be shielded from the drinking water, our product complies with EPA water safety laws.

Final safety concerns occur in the creation of our device in the Senior Design Lab. We have already performed standard safety training, and understand how to use the equipment while avoiding electrical shorts, shocks, and burns. The most dangerous would probably be soldering, as forgetting something as simple as forgetting to turn it off will create safety hazards to us and everyone in the lab. As such, safety is our priority when it comes to physical work in the design lab and we will work with at least one other person in case either find the situation dangerous, in order to adhere to rule 9 of the IEEE code of ethics [4].

Overall, we believe that we are following both Codes of Ethics [4], as we are not breaching any regulations or standards. We will keep careful note to prevent our primary controller from overheating, but otherwise no safety concerns or breaches of privacy arise.

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