U-Pong
A Modular Cup Pong Point Tracker

Design Document

Group 57
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Abstract

U-Pong is a Cup Pong point tracking device. Each unit will have two regulation-size platforms to set up the game, along with a scoreboard that is connected via Bluetooth. When all 10 cups are in their respective positions, LEDs underneath will be lit and the scoreboard will display 0. As the game is played and each cup is removed, LEDs under the removed cup will turn off and the scoreboard will increase by one. The first team that earns 10 points will be the winner. The game can be reset by replacing the cups in the designated positions. The scoreboard will automatically count down to 0 and the device will be ready for the next game.

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1 Introduction

1.1 Problem and Solution Overview

Cup Pong is a popular game played by college students everywhere. Two teams of two stand across a table from each other, with a stack of ten cups that form a triangular shape. The goal of the game is to take turns throwing ping pong balls into the cups that are filled with water across the table from them. Once a ping pong ball lands into a cup, that cup is removed. The first team to land a ball in each of the opposing team's cups is declared the winner.

The game is simple by nature only requiring a flat surface and cups. However, it is easy to lose track of the score if you are watching the game. In addition, Cup Pong is not spectator friendly as the game is not interesting unless you are on one of the teams currently playing. We plan to solve the lack of excitement by building a portable cup pong scoring system which implements LEDs into the play area as well as an LED scoreboard. The changing LED scoreboard and cup array will help hold spectator interest as well as provide information about the current game. We want to facilitate an environment that is similar to air hockey tables. Portability and ease of setup is critical as well. By integrating Bluetooth into our product, it will ensure these needs are met. Bluetooth will communicate to the scoreboard as well as the addition of rechargeable batteries for each component. This will allow users to set up their games in any location and move the scoreboard to places that best facilitate spectator interaction.

While conducting a competitor landscape analysis, we did not find any products that combine all the features we are planning into one. There is one, however, that has some sorts of similarity- which consists of a table that can be taken apart. The "RaveTable" costs $1,995.00 at the base customization [1]. The RaveTable has optical cup detection sensors and LED rings around each cup's spot. The product, however, is not battery powered.

1.2 Visual Aid

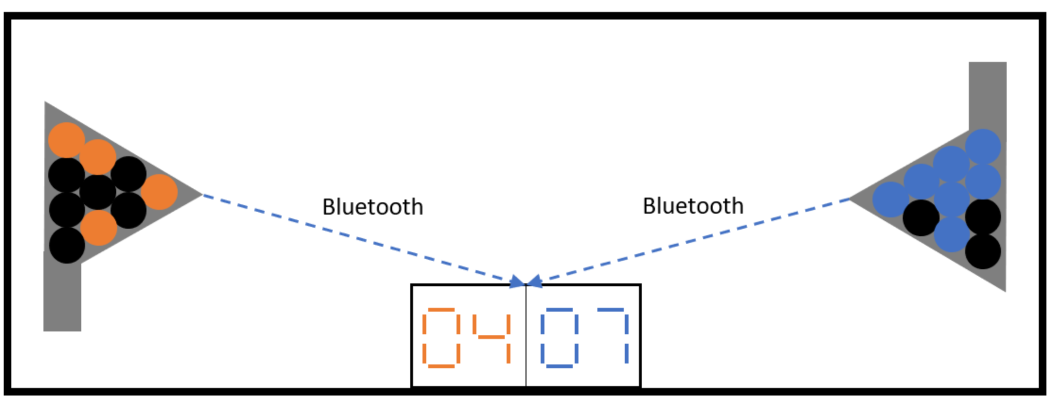


Fig. 1. High-level view of our product

Due to the game being relatively simple, the physical view of our product is also simple. There are only three main components, two triangle pads and a scoreboard. The two pads interface with the scoreboard through Bluetooth to communicate the current score. This simplicity adds ease for users and allows for portability.

1.3 High-Level Requirements List

- The IR sensors we deploy underneath each cup will detect whether a point has been scored with 90% accuracy.
- The score display will update to match the corresponding game within one second of a cup's removal from the pad.
- Each module will weigh less than 20 lbs and have a footprint no larger than 400 in^2.

2 Design

2.1 Block Diagram

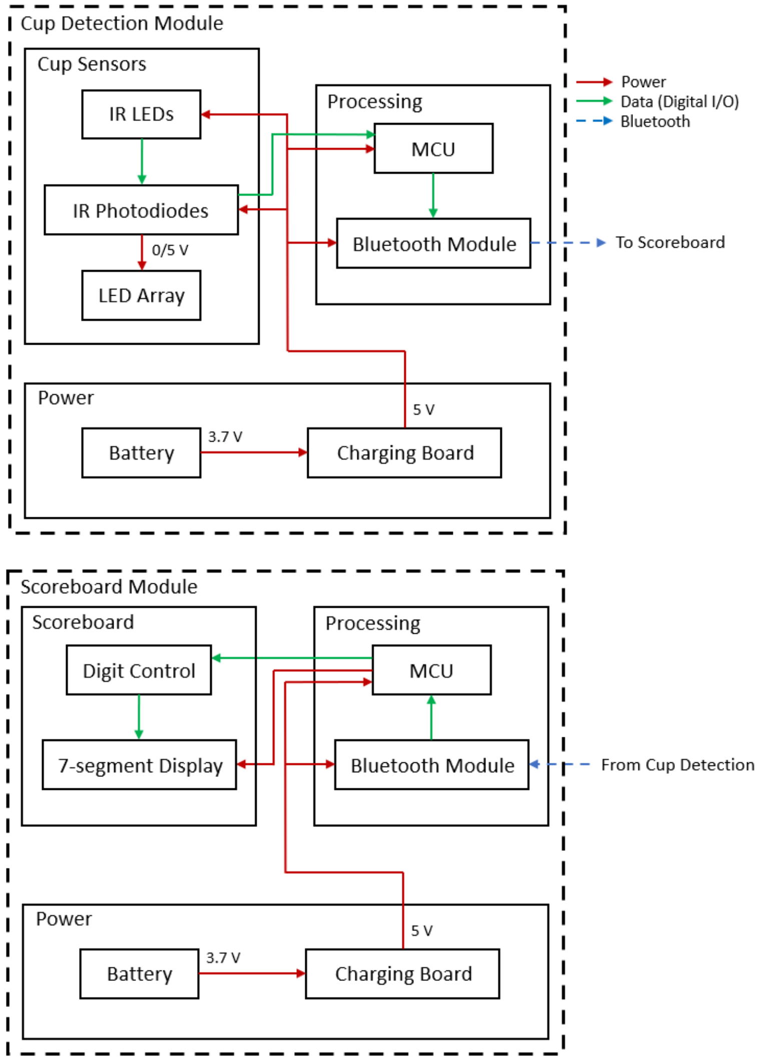


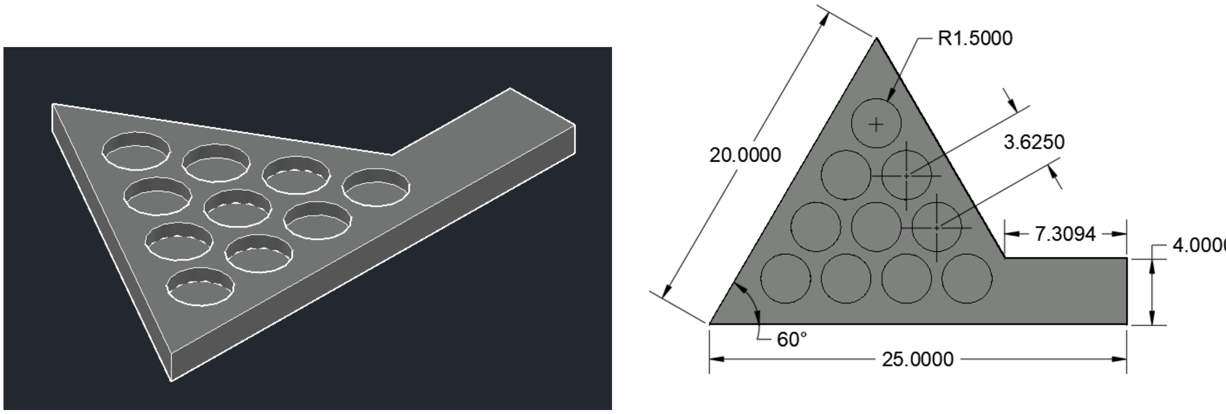
Fig. 2. Block diagram of overall product

The device is made up of two Cup Detection Modules and a Scoreboard Module. Each power subsystem will be the same, consisting of a 3.7 V Li-Po battery connected to a charging board that will boost the voltage to 5 V. The charging board's output is connected to the rest of the circuit components. The cup sensors block detects a cup using IR sensors. An IR emitter's light will be reflected back to a receiver if there is an object in range. The IR photodiode will allow current to flow through producing a voltage if a cup is present. This voltage is used to turn on and off a ring of LEDs surrounding the cup slot.

The microcontroller (MCU) in the Cup Detection Module reads the voltage across the IR photodiode to determine the number of cups removed. This data is then sent via Bluetooth to the

Scoreboard MCU. Based on how many cups are removed, the Scoreboard MCU will control which segments light up to show a number in the 7-Segment Display.

2.2 Physical Design



(a) Isometric view of Cup Detection base

(b) Dimensions of base (in)

Fig. 3. CAD drawings of Cup Detection base

Fig. 4. Final design of U-Pong

The base will be 1.5" thick with 10 slots cut to fit plastic cups. A red Solo® cup has a top diameter of 3.625" and the bottom has a diameter of 2.25" [2]. The radius of the slots we are designing provide 0.75" of room for electronics and ease of placement. In each slot, there will be six holes for LEDs and sensors. Four arranged in each cardinal direction for color LEDs and two in the middle for the IR LED and photodiode. The scoreboard is 7.5" x 5.5" with 28 LEDs arranged in a 7-segment display. The backing is a crafting foam board covered with nylon material to diffuse the light.

2.3 Subsystems

Table 1: Power Module R&V Table

Requirements	Verification
1) Adafruit Powerboost 1000C must boost the 3.7 V from the battery to 5 V (±5%).	1) a) Connect the battery to the charging board. b) Use a voltmeter to check voltage at the output is 5 V (±5%).
2) Battery charger must not exceed charging the battery to 4.2 V (±5%) and must not let the voltage drop below 3 V (±5%).	2) a) Connect the battery to the charging device for two hours. b) When the battery has reached a steady state, measure and record the voltage. c) Turn the LEDs on to let the battery drain for two hours. d) Measure and record the voltage of the battery every 15 minutes.

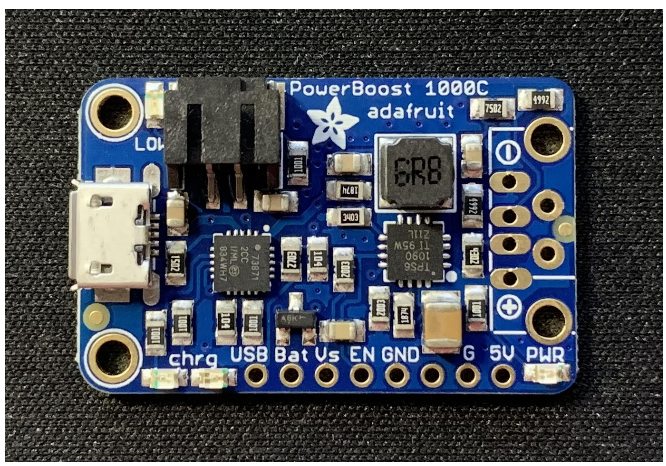


Fig. 5. Adafruit Powerboost 1000C board

The power module is the same across all three instances in the device. Each contains a 3.7 V Li-Po rechargeable battery with a JST connector to an Adafruit Powerboost 1000C board. The charging board will provide the battery the needed over/undervoltage protection. The charging board also has pass through power which simplifies the user experience as our device can be easily charged through a micro-USB connector. The boost board will increase the voltage to 5 V which is enough to power every component of our design.

Table 2: Scoreboard Processing Module R&V Table

Requirements	Verification
1) Bluetooth module must receive data from the Cup Detection Module.	1) a) Connect the Bluetooth module to the RX and TX ports on the MCU and power the module. b) Use a simple script to send integer data from the Cup Detection Module to the scoreboard Bluetooth module. c) Use a terminal on the scoreboard side to determine if the data is being received.
2) Send data to the LED display.	2) a) Send data containing the from the integers 1 to 10 from the MCU to segments A-G (see Fig. 7). b) Verify that the segments are lit up.

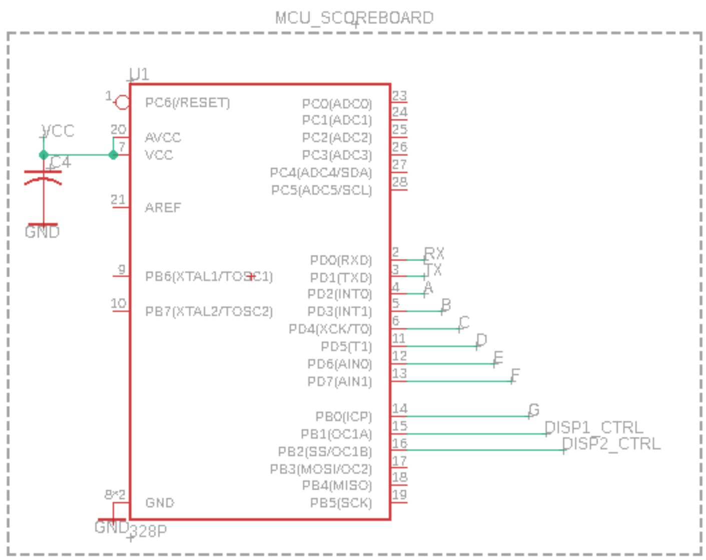
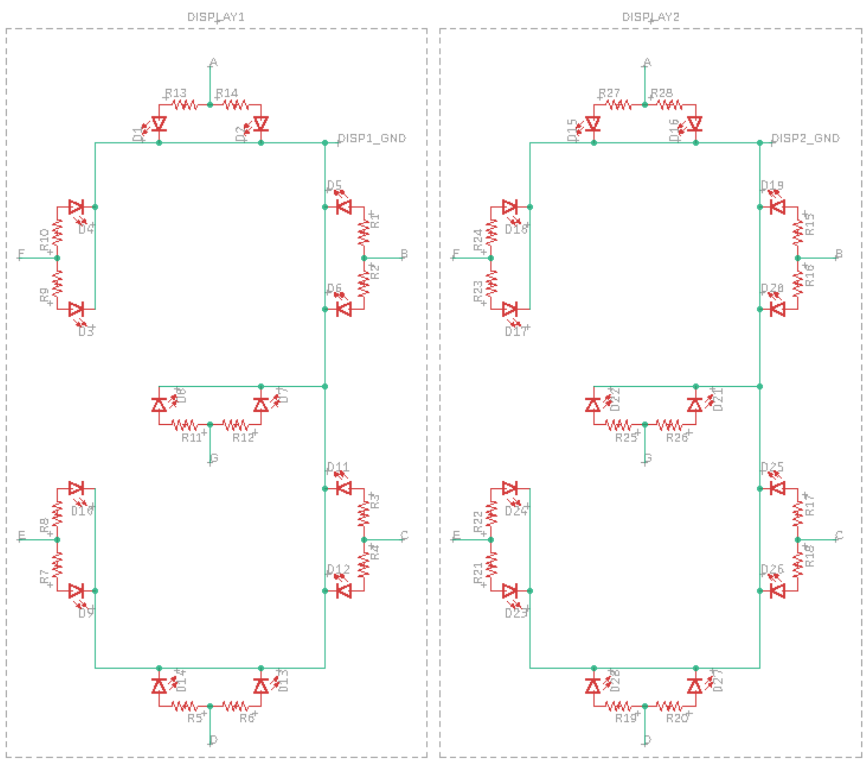


Fig. 6. Scoreboard microcontroller circuit schematic

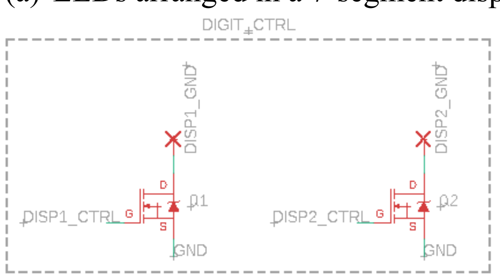
The scoreboard MCU will take data from the Bluetooth through the RX pin. This data will be used to determine how many cups have been removed. Digital pins are connected to the respective segments of the LED display. “DISP1(2)_CTRL” is connected to the gate of an NMOS acting as a select bit. Source is grounded with drain connected to the cathode of all the LEDs in the display. Whichever MOSFET receives a high gate signal updates the respective LED segment to the correct number. This process will loop through at a frequency higher than a human can perceive to emulate a solid light.

Table 3: Scoreboard Module R&V Table

Requirements	Verification
1) Must count up from zero as cups are removed.	1) Start with all 10 cups in position. Remove the cups and verify that the number increases (will stop at 10).
2) Number increases within one second of a cup being removed.	2) Repeat verification (1), however, time the removal of the cup and the display updating using a stopwatch. The display should change almost immediately.



(a) LEDs arranged in a 7-segment display



(b) Digit control MOSFETs

Fig. 7. LED 7-Segment LED display circuit schematic

A 7-segment display consists of seven individually lit up segments to produce different numbers. For example, to display a “1” segments A, B, C, D, E, F of DISPLAY1 are lit up for a “0” and segments A and B are lit up for a “1”. The digit control bit is managed by the gate signal of an NMOS (see section 2.3.2).

Table 4: Cup Detection Processing Module R&V Table

Requirements	Verification
1) Take data from IR photodiode.	1) a) Connect a voltmeter to the data input pin on the MCU. b) Verify that when a cup is removed the data input pin has low signal.
2) Send data to Scoreboard Module’s MCU through Bluetooth.	2) a) Connect the Bluetooth module to the RX and TX ports on the MCU and power the module. b) Connect to the Bluetooth module in the Scoreboard Module. c) Connect the receiver Bluetooth module to an Arduino Uno. d) Confirm through the terminal that data is sent and received.

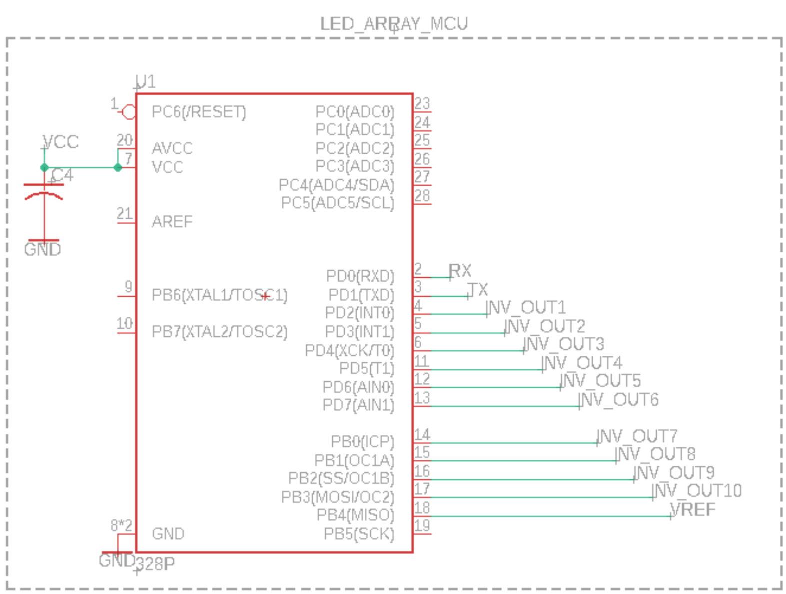


Fig. 8. Cup detection MCU circuit schematic

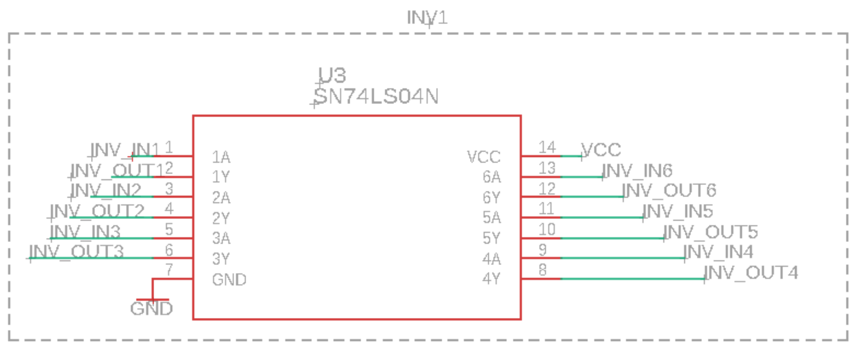


Fig. 9. Inverters (1-6) connected to MCU circuit schematic

The digital pins connected to the inverter outputs are measuring the voltage across the LEDs in the cup sensors. The digital pins will receive a high signal if a cup has been removed and a low signal if a cup is still present. The MCU will compute the number of cups left and send the data to a Bluetooth module that transmits to the scoreboard MCU. Fig. 9 above shows six of ten inverters connected to the MCU. The inverters act as LED drivers as well to supply enough voltage and current.

Table 5: Cup Sensing Module R&V Table

Requirements	**Verification**
1) Detect if a cup is currently in the designated slot.	1) a) Connect an IR LED and Photodiode to the base and a power source. b) Read the voltage across the IR sensor and confirm it changes when a cup is removed.
2) LEDs must be on when a cup is detected and turn off once a cup is removed.	2) a) Place all the cups in the correct positions on the board and confirm the LEDs are on. b) After removing a cup, ensure that the LED ring turns on.
3) LEDs must draw the respective voltages needed,1.8V (±5%) for orange and 3V (±5%) for blue, at 20 mA (±5%).	3) a) Connect voltmeter to an LED. b) Put a cup into the LED's slot. c) Record voltage and current of LED every 15 minutes.

IR LEDs will be placed next to photodiodes in each of the ten cup slots. Four LEDs will be wired in parallel and placed in four cardinal directions of the circular slot. A photodiode will produce a low voltage when an IR wave is reflected back to it, and a high voltage when no reflection is detected. This voltage is sent directly to the MCU as well as an inverter. The MCU will use the built in voltage thresholds to determine a high or low signal. The inverter output will power the LEDs in the ring. If a cup is detected, the LEDs will be on with the respective team colors. If a cup is removed, the LEDs will turn off.

Table 6: Bluetooth Modules R&V Table

Requirements	Verifications
1) The transmitter module must communicate with the respective receiver module with no interference from the other pair.	1) a) Connect the two pairs of Bluetooth modules. b) From the first transmitter module, run a script to send a "0" to the first receiver module. c) Repeat for the second transmitter module, but send a "1" to differentiate the data sent. d) Ensure the correct receiver is obtaining the accurate digital signal.

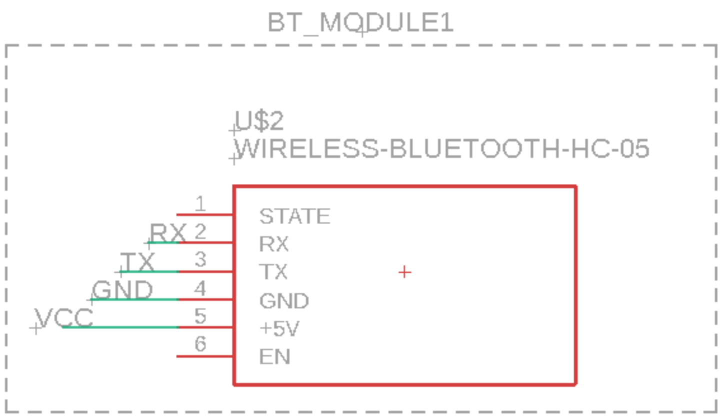


Fig. 10. Bluetooth module circuit schematic

We will have four Bluetooth modules in our design. Two will be for sending data from the cup detection modules and two will be used for receiving these messages for the scoreboard. The RX pin is for receiving data and the TX pin is for transmitting data. These two pins will be connected to digital pins 0 and 1.

2.4 Tolerance Analysis

In our design we currently have four LEDs in each slot to produce light visible enough for players to see. We can wire the LEDs in parallel or series which each have their tradeoffs. With forward voltages of 1.8 V for orange and 3 V for blue, 5 V is enough to drive one to two LEDs in series. This is also simpler in practice for wiring and soldering. However, in parallel, voltage will stay constant and the current will split between branches. This allows us to drive the four LEDs desired. Recommended current for LED is <~20 mA. We set the desired current to be ~10 mA. Currently our design uses four LEDs. We can either use a single resistor before the parallel branches, or use four resistors inside each branch. For a single resistor, it will dissipate 40 mA of current. With V_{cc} = 5 V, Using Ohm's Law in (1), we can determine a resistor size of 50 **Ω**.

$$R = \frac{5-3}{0.04} \tag{1}$$

If we use four resistors, (2) shows a resistor size of 200 **Ω** for 3.3 V and 20 mA through each branch.

$$R = \frac{5-3}{0.01} \tag{2}$$

Based on these calculations, using individual resistors will be safer as each resistor will need to dissipate less current. A small resistor dissipating too much current will heat up faster which can lead to dangerous conditions. In the end we decided on using four resistors of 220 **Ω**. This allows the LEDs to turn on and be bright enough for our use case.

We decided to make the tradeoff to control the LED color of each slot through the voltage change of the IR sensor rather than sending the data from the IR sensor to the MCU and then control the color from there. This decreases the number of pins that we have to dedicate towards LED control, potentially removing the need for an extra MCU, and simplifies the wiring that we will have to do later on. However, this does mean that we have to create a PCB for the inverter to connect to the LEDs and need to do more testing to ensure that we can consistently read the voltage of the colored LEDs in order to check if there is a cup in the slot or not.

3 Cost and Schedule

3.1 Cost Analysis

As of 2018-2019, the average salary for an Electrical Engineer who graduated from UIUC is $79,714. [3] Converting this salary to an hourly wage would equate to roughly $38.32/hr. The following equation is used to calculate total pay required for one member of this project. $38.32/hr(hourly wage) * 2.5 * 15hrs/week * 12 weeks = $17,244. For the three members working on this project, the total cost of labor would be $51,732.

3.2 Parts

Table 7: Parts List

Description	Manufacturer	Part #	Quantity	Cost
ATmega328P 28-PDIP Microcontroller	Microchip Technology	ATMEGA328-PU	4	$2.30 ×4 = $9.20
100 pcs LEDs (Orange/Blue)	EDGELEC	N/A	2	$6.15 × 2 = $12.30
100 pcs 940 nm IR Emitter	Chanzon	N/A	1	$6.74
100 pcs 940 nm IR Receiver	Chanzon	N/A	1	$8.22
HC-05 Bluetooth Module	HiLetGo	N/A	4	$7.99 × 4 = $31.96
3.7 Rechargeable LiPo Battery	EEMB	103454	3	$14.50 × 3 = $37.50
Adafruit PowerBoost 1000C	Adafruit	B01BMRBTH2	4	$19.94 × 4 = $79.76
LeMotech ABS Plastic Electrical Project Case	LeMotech	Lm201805132201	3	$9.99 × 3 = $29.97
MOSFET N-CH	ON Semiconductor	FDP8880	4	$1.25 × 4 = $5
			Total Cost	$220.65

4 Conclusion

4.1 Accomplishments

By the time of our final demonstration, we were able to successfully integrate all parts of the project that we outlined in the Design Document. This includes the cup sensing and processing module, Bluetooth module, Scoreboard module, and software to control the Scoreboard display.

4.2 Ethical Considerations

Our project relates to a popular college drinking game. User safety is always the top priority. Although we are not directly promoting consuming alcoholic beverages, we recognize that our end users will most likely be using it for that purpose. As an extension, we will in no way encourage underage drinking or over-drinking in accordance with federal law. In reference to IEEE Code of Ethics, we "hold paramount the safety, health, and welfare of the public" [4]. If any user suspects unlawful activity as a result of the use of our product, we recommend immediately contacting authorities.

Use of LEDs creates the risk of triggering seizures in those with photosensitive epilepsy. Flashing lights and patterns are particularly high risk. Flashes between 5-30Hz in particular are dangerous [5]. Although our LEDs will not be flashing in our design we will include an epilepsy warning sticker on our device to keep users aware.

Liquids near electronics pose a hazard. We plan on using XPS foam boards for our base. This type of foam is waterproof and will not absorb water compared to other materials such as wood [6]. If needed, we will add a coating of a waterproof seal. We recommend our users to ensure they are not creating a dangerous environment due to spillage.

All of the modules in this product will be powered via rechargeable LiPo batteries. To minimize risk of injury, these parts will be securely enclosed. We will add warning labels for practicing safe battery usage such as, not smoking or creating an open flame near the battery enclosures. In addition, it will be recommended to keep away from direct sunlight, high temperatures, and high humidity [7].

4.3 Future Work

If we were to continue working on this product past the current scope, there are a few things we are considering adding. First, we would like to appeal to a larger audience. Since we expect our product to be used in a numerous amount of environments, we think it would be a good idea to create both larger and smaller scoreboards. In doing so, areas that are more open can advertise the score a bit easier. Second, we would like to brand our product as Illini-themed. We would design one pad, LED array, and LED scoreboard to be blue, and the other as orange. Lastly, we would like to add sound effects. Our vision was to play an audio track whenever a point is scored, and then an extra sound when a team wins the game.

5 References

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