Cup Pong Scoring Device

Design Document

Group 57
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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. To solve these issues, we will build a portable cup pong scoring system which implements LEDs into the play area as well as an LED scoreboard. Our idea is to facilitate an environment that is similar to air hockey tables. Portability and ease of setup is critical. The integration of Bluetooth into our product 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

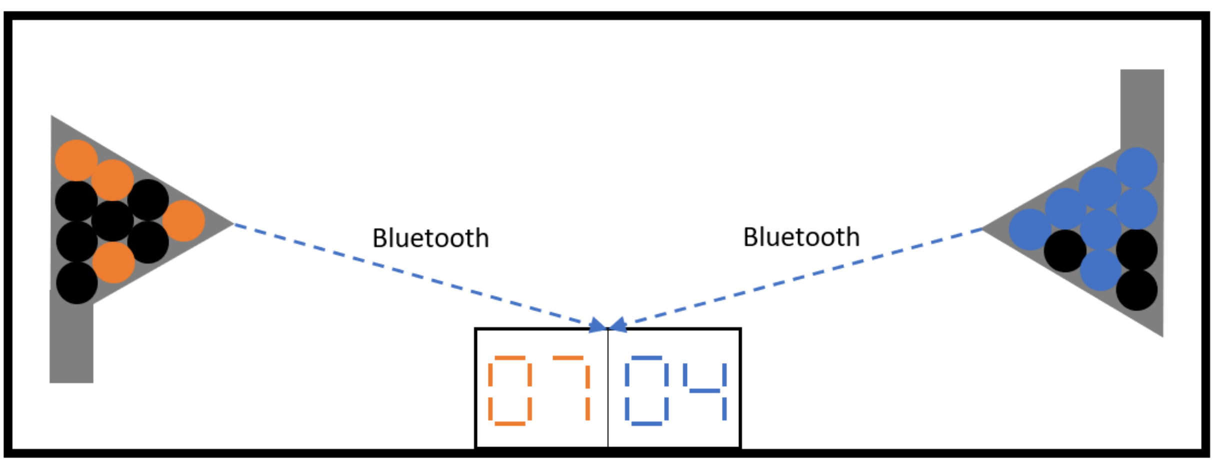

Fig. 1. High-level view of our product

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 be less than 20 lbs and have a footprint no larger than 400 in^2.

2 Design

2.1 Block Diagram

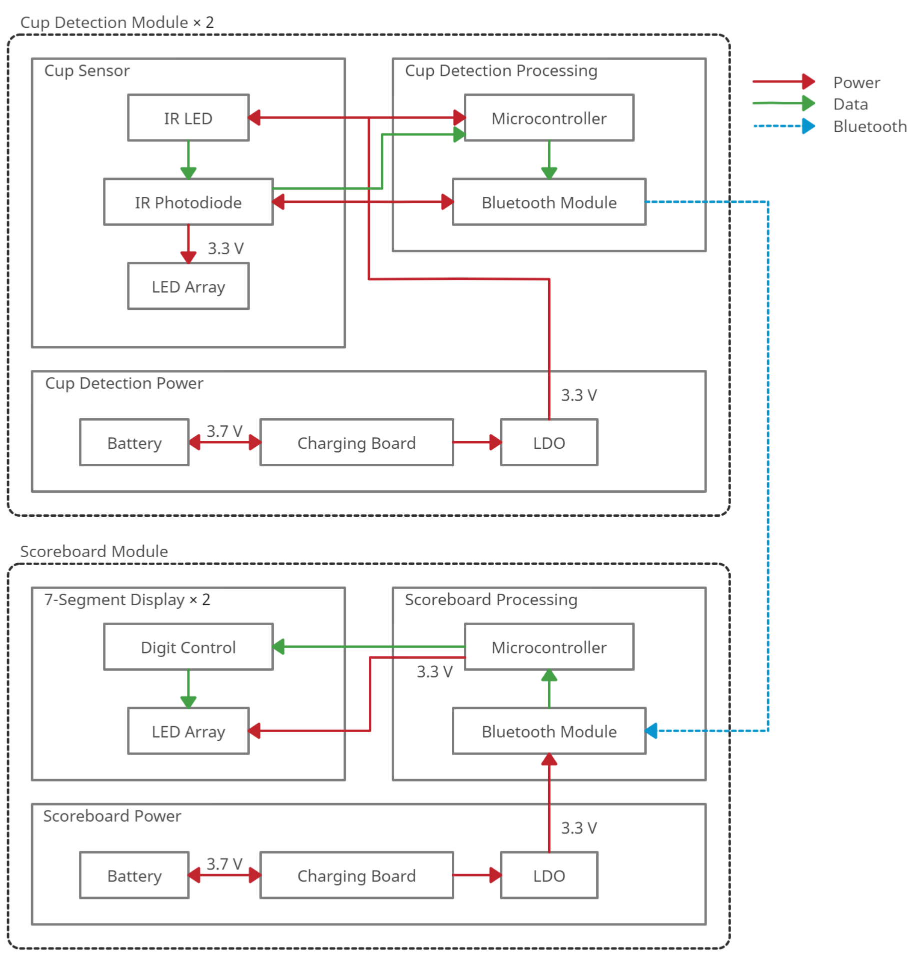

Fig. 2. Block diagram of overall product

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 with pass through. The charging board's output is then connected to an LDO to regulate the voltage to 3.3 V. The cup sensor 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 using 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

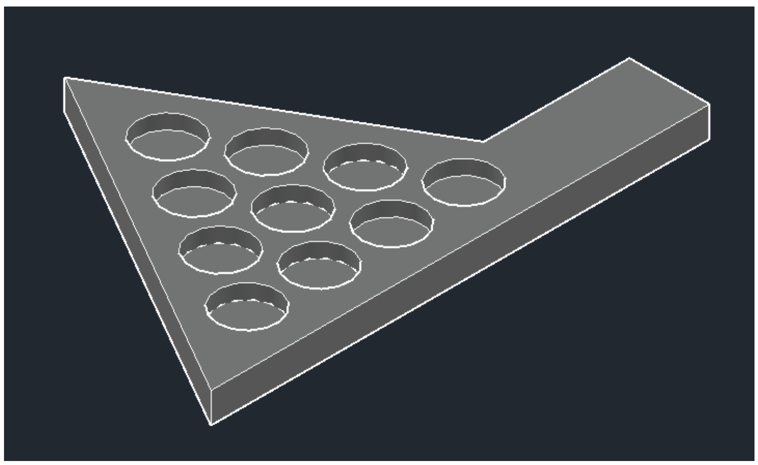

Fig. 3. Isometric view of cup detection base

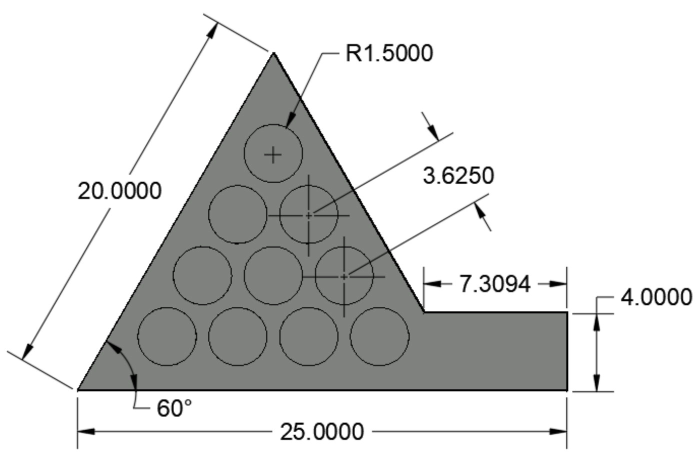

Fig. 4. Dimensions of base (in)

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.

2.3 Subsystems

Table 1: Power Module R&V Table

Requirements	Verification
1) LDO converts 3.7 V to 3.3 V (±5%) needed to power components.	1) a) Connect the charging board output to LDO. b) Use a voltmeter to check voltage at the output is 3.3 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) Attach voltmeter probes to the JST connector pins of the battery. b) Connect the battery to the charging device for two hours. c) When the battery has reached a steady state, measure and record the voltage. d) Turn the LEDs on to let the battery drain for two hours. e) Measure and record the voltage of the battery every 15 minutes.

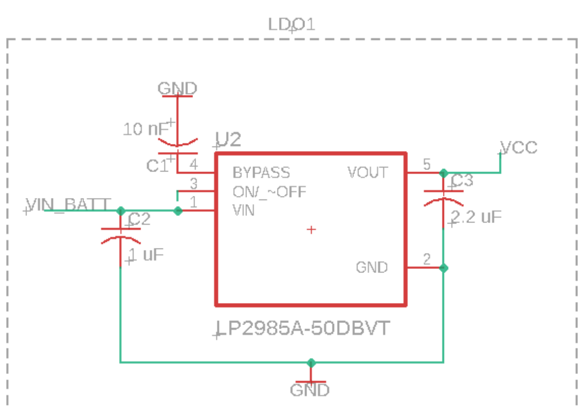

Fig. 5. LDO circuit schematic

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 a charging 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 USB mini-B connector. The LDO will regulate the voltage to 3.3 V which is enough to power every component of our design. Instead of connecting components directly to the battery, the LDO will account for voltage spikes to ensure a constant 3.3 V. If too much ripple is present components may be damaged.

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.

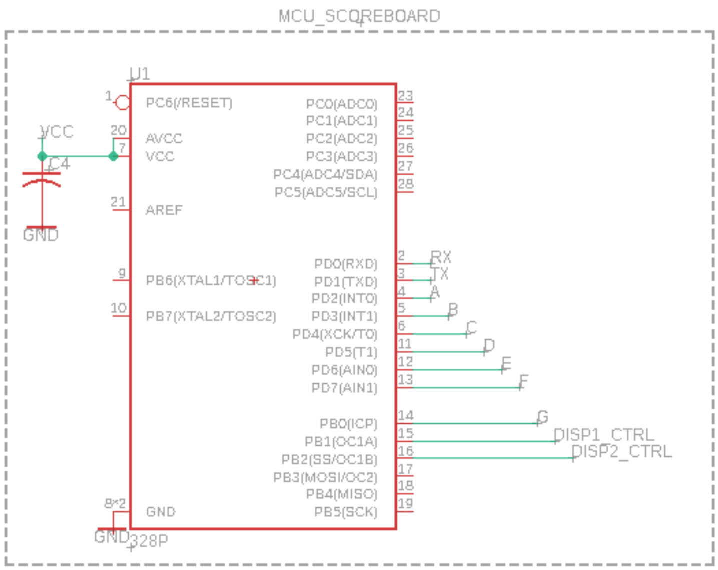

Fig. 6. Scoreboard microcontroller circuit schematic

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.

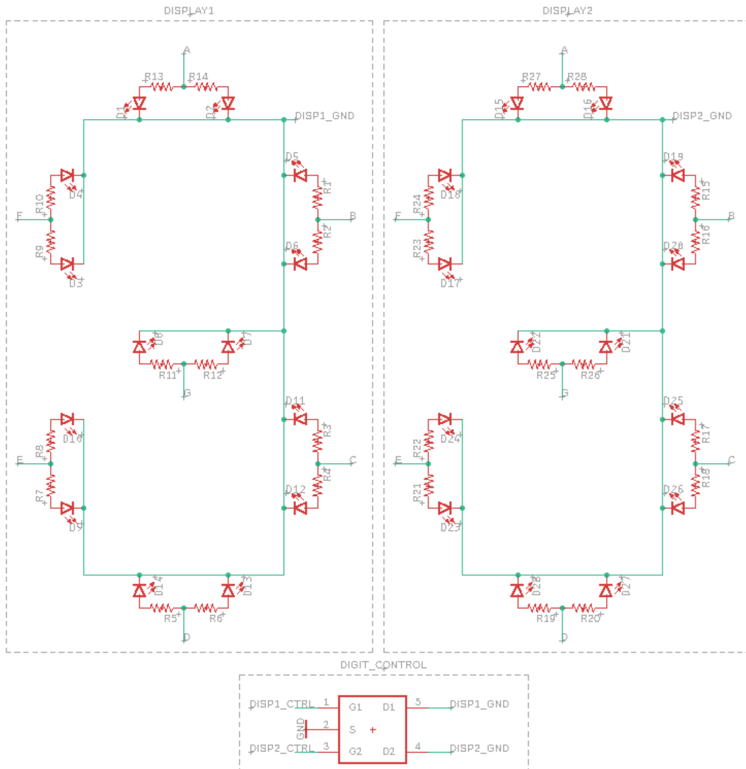

Fig. 7. LED 7-Segment LED display circuit schematic

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.

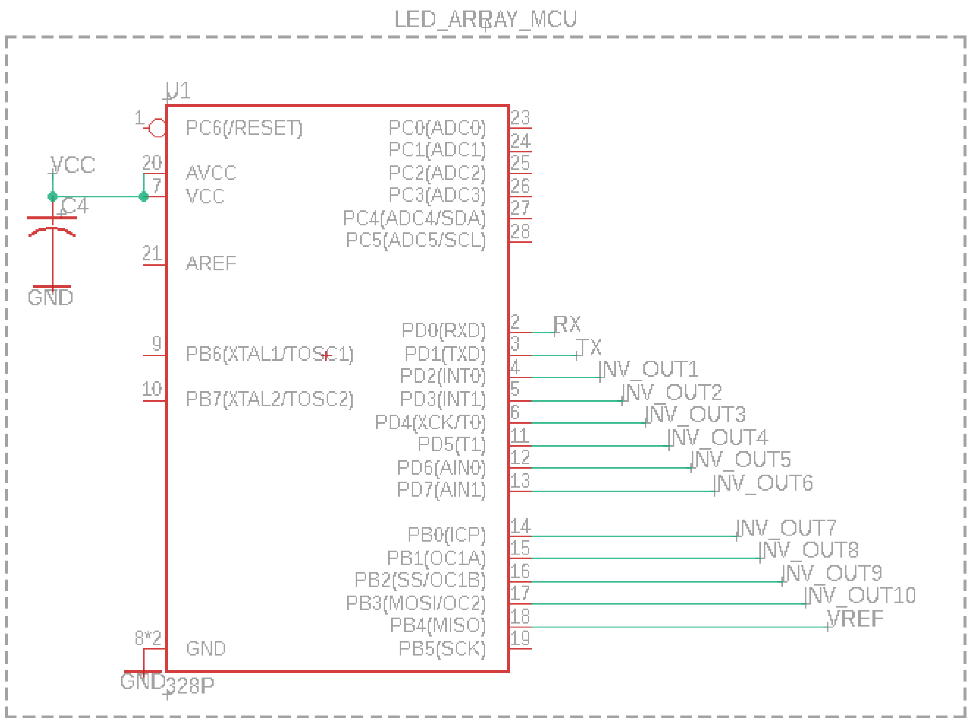

Fig. 8. Cup detection MCU circuit schematic

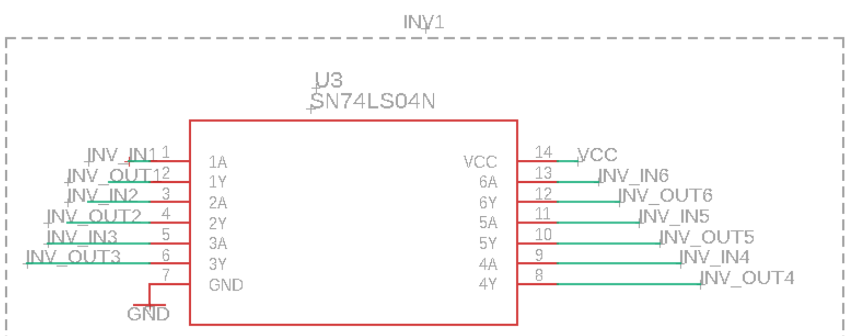

Fig. 9. Inverters (1-6) connected to MCU circuit schematic

The digital pins connected to the inverter outputs are measuring the voltage across the LEDs in the cup sensors. Before the signal is inverted, the voltage from the photodiode is sent through a comparator to produce a definitive high or low voltage. 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.

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) Using voltmeter read the voltage across the IR sensor when the cup is in the slot and confirm that it changes when a cup is removed.
2) LEDs must be off by default. LEDs must turn on (orange or blue, depending on the team) once a cup is removed.	2) a) Place all the cups in the correct positions on the board. b) When the board is connected to a power source, ensure the LEDs are off. c) 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.

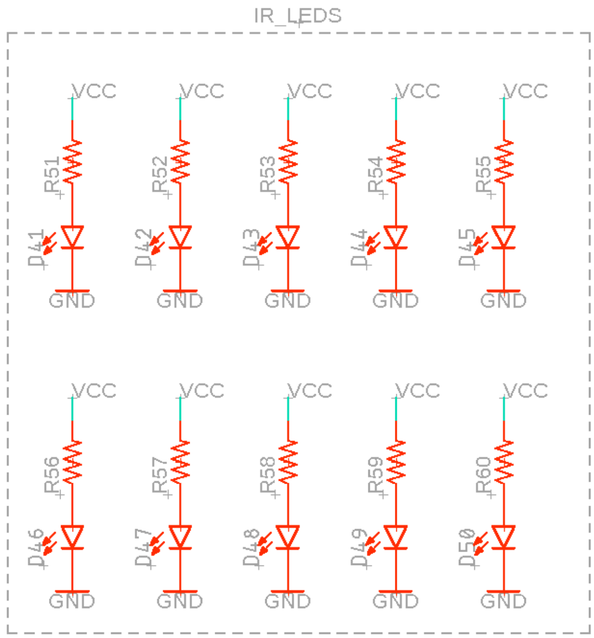

Fig.10. IR LEDs circuit schematic

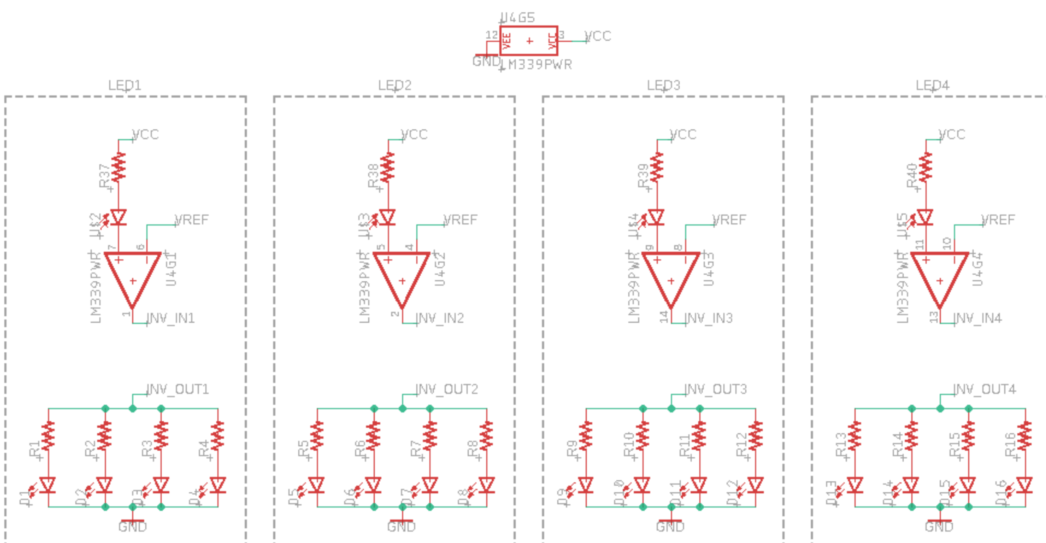

Fig. 11. Photodiode and LED ring circuit schematic

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 high voltage when an IR wave is reflected back to it, and a low voltage when no reflection is detected. This voltage is sent through a comparator to determine a high or low signal. After the high/low signal is sent through an inverter, this will power the LEDs in the ring. If a cup is detected, the LEDs will be off. If a cup is removed, the LEDs will turn on with the respective team colors.

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 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.

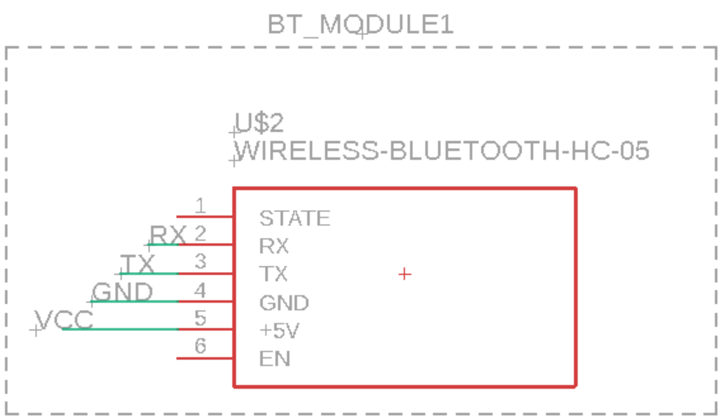

Fig. 12. Bluetooth module circuit schematic

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, 3.3 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. Recommended current for LEDs are around 20 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 80 mA of current. Using Ohm's Law in (1), we can determine a resistor size of 41.25 **Ω** for 3.3 V and 80 mA

$$R = \frac{3.3}{0.08} \tag{1}$$

If we use four resistors, (2) shows a resistor size of 165 **Ω** for 3.3 V and 20 mA through each branch.

$$R = \frac{3.3}{0.02} \tag{2}$$

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.

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
2 N-Channel MOSFET	Diodes Incorporated	DMN32D2LDF-7	2	$0.52 × 2 = $1.04
5 V 150 mA LDO	Texas Instruments	LP2985A-50DBVT	4	$0.60 × 4 = $2.40
USB LiIon/LiPoly charger - v1.2	Adafruit	259	4	$12.50 × 4 = $50
Plastic Electronics Enclosure	Polycase	XR-46F	3	$7.48 × 3 = $22.44
Quad Differential Comparator	Texas Instruments	LM339NE3	6	$0.55 × 6 = $3.30
HC-05 Bluetooth Module	HiLetGo	N/A	4	$7.99 × 4 = $31.96
6 Channel Inverter	Texas Instruments	SN74LS04N	4	$0.83 × 4 = $3.32
3.7 Rechargeable LiPo Battery	EEMB	103454	3	$14.50 × 3 = $37.50
			Total Cost	$179.42

Quoted Machine Shop Labor Cost: $56.12/hr for 5-6 hours (averaged to 5.5 hours for total cost)
Total Cost of Project: $51,732 + $133.93 + $308.66 = $52,174.60

3.3 Schedule

Table 8: Schedule

Week	Albert	Dylan	Kyle
2/15	Create work flow chart to help generate project ideas.	Research past projects to understand complexity requirements.	Begin sourcing useful electrical component merchant websites.
2/22	Work on initial circuit	Make initial block	Fabricate initial physical

	schematic for all modules.	diagram and understand high level requirements.	design, including cup fastening dimensions.
3/1	Restructure circuit schematic based on DDC comments.	Research requirements for Bluetooth controlled scoreboard.	Make content changes for DD on most written parts.
3/8	Work with Machine Shop to get prototype of physical design.	Continue researching Bluetooth requirements.	Finalize all required parts for project and bring to order.
3/15	Finalize PCB schematics for all modules.	Do research on creation of LED scoreboard array.	Start researching how to interface MCU with software.
3/22	Test all ordered parts to ensure they are properly working.	Create scoreboard array based on research done earlier.	Write software that handles cup LEDs.
3/29	Ensure physical design is ready to go for PCB installation.	Create scoreboard array based on research done earlier.	Begin writing software that handles the counting on scoreboard.
4/5	Work on PCB installation/soldering.	Install LEDs underneath all cups.	Finish writing software that handles the counting on scoreboard.
4/12	Continue working on PCB installation/soldering.	Ensure all subsystems properly communicate.	Begin creating outline and required sections for final paper.
4/19	Finalize all minor details of product.	Finalize all minor details of product.	Assign sections for each group member for demo.
4/26	Work on final paper.	Work on final paper.	Work on final paper.
5/3	Present final product.	Present final product.	Present final product.

4 Discussion of Ethics and Safety

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].

5 References

[1] “RaveTable Interactive LED Beer Pong Table,” Chexal. [Online]. Available: https://chexal.com/product/ravetable. [Accessed: 17-Feb-2021].

[2] “Beer Pong Cups Dimensions & Drawings,” *RSS*. [Online]. Available: https://www.dimensions.com/element/beer-pong-cups. [Accessed: 05-Mar-2021].

[3] Grainger Engineering Office of Marketing and Communications, “Salary Averages,” *Electrical & Computer Engineering | UIUC*. [Online]. Available: https://ece.illinois.edu/admissions/why-ece/salary-averages. [Accessed: 03-Mar-2021].

[4] “IEEE Code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 05-Mar-2021].

[5] E. Wirrell, “Photosensitivity and Seizures,” Epilepsy Foundation, 30-Sep-2019. [Online]. Available: https://www.epilepsy.com/learn/triggers-seizures/photosensitivity-and-seizures. [Accessed: 19-Feb-2021].

[6] “What is the Difference Between XPS and EPS Insulation?”, SOPREMA UK, [Online]. Available: https://www.soprema.co.uk/en/article/sopravoice/what-is-the-difference-between-xps-and-eps-insulation

[Accessed: 27-Mar-2021].

[7] “Warnings for Using Batteries,” *BatterySpace.com/AA Portable Power Corp. Tel: 510-525-2328*. [Online]. Available: https://www.batteryspace.com/warningsforusingbatteries.aspx. [Accessed: 03-Mar-2021].