AUTOMATED NBA GAME CLOCK STOPPER

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Abstract

This project utilizes ambient light sensing technology mounted on a basketball net to stop the game clock when a shot is made. Ultimately, every subsystem of the final design was verified through unit testing, and the system correctly classifies over 90% of attempted shots as either made or missed. The game clock stops on made shots and continues running for missed shots. Although the resulting system is too sensitive to fluctuations in standard environments, the constant lighting conditions within a basketball stadium would alleviate this concern.

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1. Introduction

1.1 Purpose and Functionality

Within the last two minutes of an NBA game, the game clock is supposed to stop immediately after each made shot. This process is currently done manually by a game clock operator. However, as viewers, we have seen delays in this manual stopping of the clock due to human reaction speed. An example of this can be seen in Game 6 of the 2013 finals where Ray Allen hit a game-tying 3 pointer with 5.2 seconds left on the clock. However, after looking at the replay we can see that the ball actually clears the net with 5.5 seconds left on the clock [1]. Another example can be seen in game 5 of the 2021 Finals where Khris Middleton makes a layup in a close game. The clock stops at 27.2 seconds, but when looking at the replay we see that the clock should have stopped at 27.5 seconds [2]. Three-tenths of a second may seem like an insignificant amount of time, but according to the Trent Tucker rule [3], 0.3 seconds is the minimum amount of time required to inbound the basketball and attempt a shot. If the game clock displays less than 0.3 seconds approaching the end of the game, the shot will be waived off. There have been numerous similar instances of delayed clock stoppage throughout past seasons and playoffs. Multiple delays within the same game can mount to create enough time for teams to design and run complex plays. In summary, an accurate stoppage of the clock is crucial for close games as every three-tenths of a second is enough time for another possession, which can influence the outcome of the game. To solve this problem, we developed a system that tracks when the ball goes through the hoop and immediately stops the game clock. This was accomplished by using an ambient light sensor system integrated into the net. The key functionality of our solution is to detect a made shot, which is done by measuring the decrease in ambient light level associated with a made shot, and subsequently stop the clock within 0.3 seconds. This marks a significant improvement over the average human reaction time.

1.2 Subsystem Overview

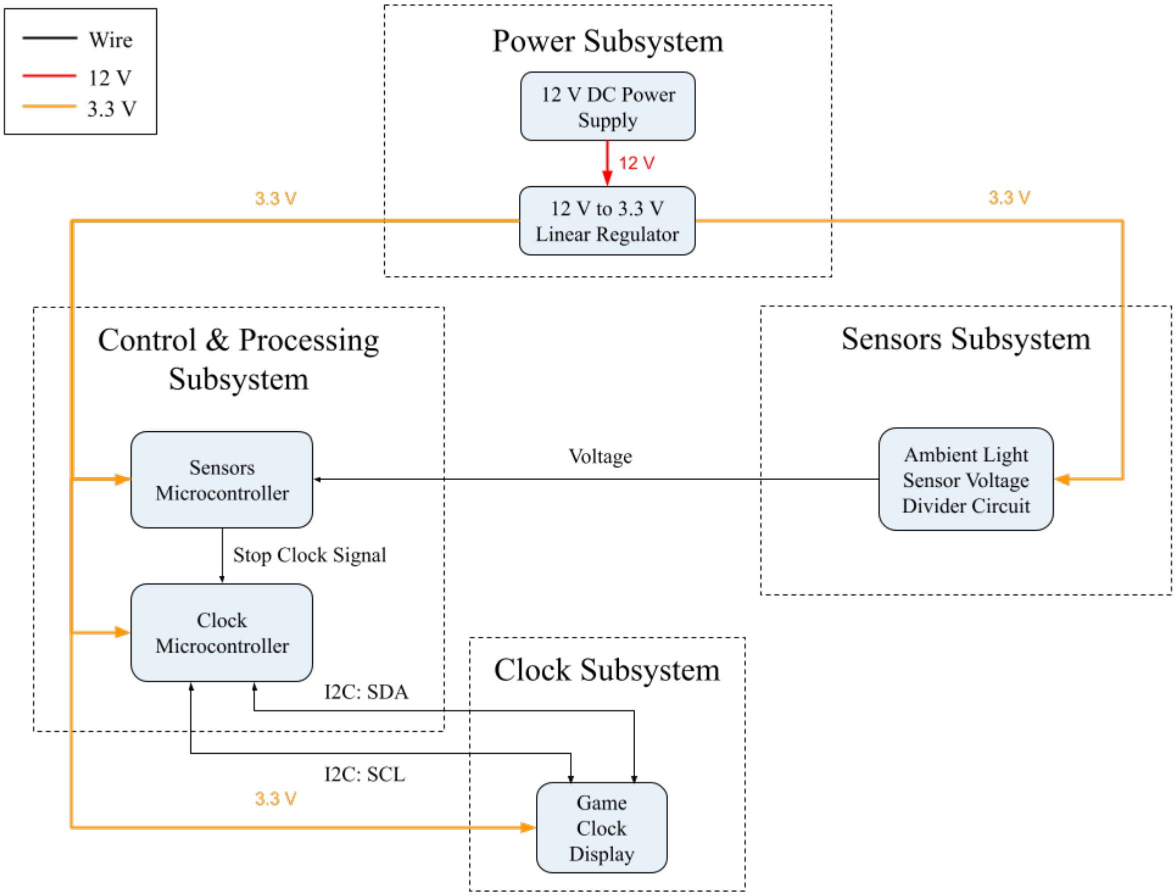

Figure 1. Block diagram of system.

The product is broken down into four main subsystems: Power, Sensor, Control & Processing, and Clock. The Power Subsystem is responsible for providing the appropriate voltage to all components in each subsystem. The Sensor Subsystem is responsible for detecting the ambient light level at the bottom of the net and converting this light level to a voltage that is sent to the Control & Processing Subsystem. The Control & Processing subsystem is responsible for analyzing the voltage input from the Sensor Subsystem and sending a signal to stop the game clock when this voltage input is below a certain threshold (which indicates a made shot). The Clock Subsystem is responsible for displaying the time left in the game. The clock display will stop when it receives the aforementioned signal from the Control & Processing Subsystem.

2. Design

2.1 Design Procedure

Early stages of our design consisted of thermal, optical, and infrared sensors. The purpose of the thermal sensor was to differentiate the ball from a player's hand. However, we had concerns about the heat signature from the ball falsely triggering the sensor, so we decided against this solution.
The revision that followed consisted of a time-of-flight sensor, optical sensor, and computer vision. The combination of these three sensors would provide a comprehensive view of the ball as it travels near the basket, successfully identifying made shots. However, due to the learning curve associated with computer vision and time of flight sensors, the design would prove to be too difficult to implement in the scope of the semester.

The next iteration was with an optical, color, and ultrasonic sensor. The optical sensor would be placed behind the backboard, overlooking the rim. The color and ultrasonic sensors would then be mounted directly below the rim. A setup like this would allow for us to make sure the upper sensor is triggered before the two bottom sensors, indicating that a ball has passed through the net in the proper direction. The optical sensor would confirm that the ball is within the range of the rim, the ultrasonic sensor would confirm that the ball has passed through the rim, and the color sensor would prevent a false trigger from a hand. The caveat of this design was the inaccuracy of ultrasonic sensors and the uncertainty with getting the same color from the ball each time it passes through the net, depending on the lighting on the ball.

With advice from the professors and TAs, we began exploring ways to mount sensors directly onto the net. The problem was then reduced to one of proximity detection within the net. This led us to ambient light sensors that utilize I2C communication. In a system with five sensors, four would be placed on the net five inches below the rim. At this position, the ball would be halfway down the rim with minimal chance to bounce out. These sensors would be placed circularly around the center of the net at 90-degree increments. Furthermore, we would have a fifth ambient light sensor placed at the bottom of the net. A shot is considered “officially made” when the basketball passes the bottom of the net, so this fifth sensor would be used to stop the game clock at the correct time [4]. All five sensors would connect to the PCB, constantly outputting signals that indicate the level of ambient light. Our PCB would then determine if the clock needs to be stopped and send an appropriate signal to stop the clock when a shot is made. While using these sensors, we were not able to get the I2C communication working properly, so we had to look toward alternatives.

As a simpler form of ambient light sensing, our initial thoughts were to switch every I2C ambient light sensor to a photoresistor. However, due to the limitations of the ADC pins available on our microcontroller, we could only implement one photoresistor for our final design. This photoresistor is located at the bottom of the net. Since the bottom of the net is significantly narrower than the width of the basketball, we determined that one sensor would still accurately detect a made shot.

2.2 Design Description

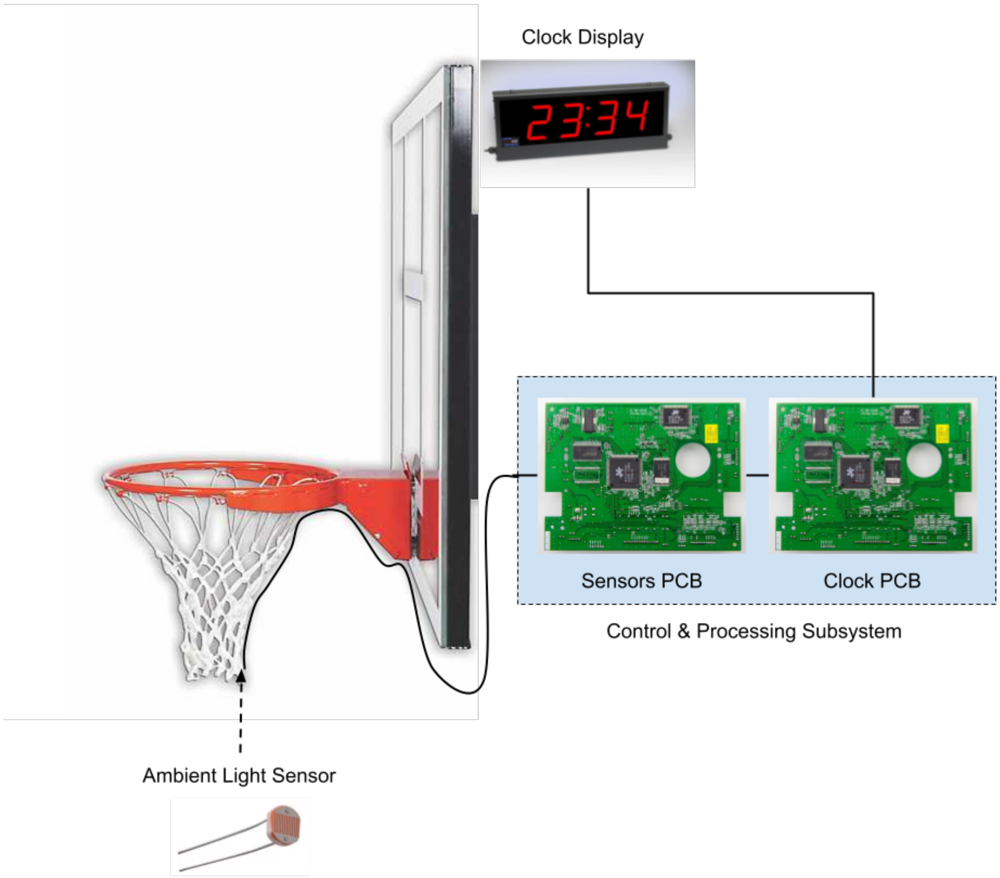

Figure 2. Visual aid of final design.

Figure 2 shows a visual representation of our system. The ambient light sensor will be attached at the bottom of the net and will connect to the Sensors PCB of the Control & Processing Subsystem. The two PCBs of the Control & Processing Subsystem will be attached to the back of the backboard in a box. This will ensure that the Control & Processing Subsystem will be protected from the basketball and any game play activities. The Clock PCB controls the clock display which is mounted at the top of the backboard.

2.2.1 Power Subsystem

The Power Subsystem consists of a 12 V DC power supply [5] and a linear voltage regulator [6]. The linear regulator converts the 12 V provided by the DC power supply to 3.3 V, which is compatible with all our components. We considered using a buck converter in place of a linear regulator, but we eventually decided that the higher efficiency of the buck converter was not worth the tradeoff of a higher power supply noise and complexity for our system.

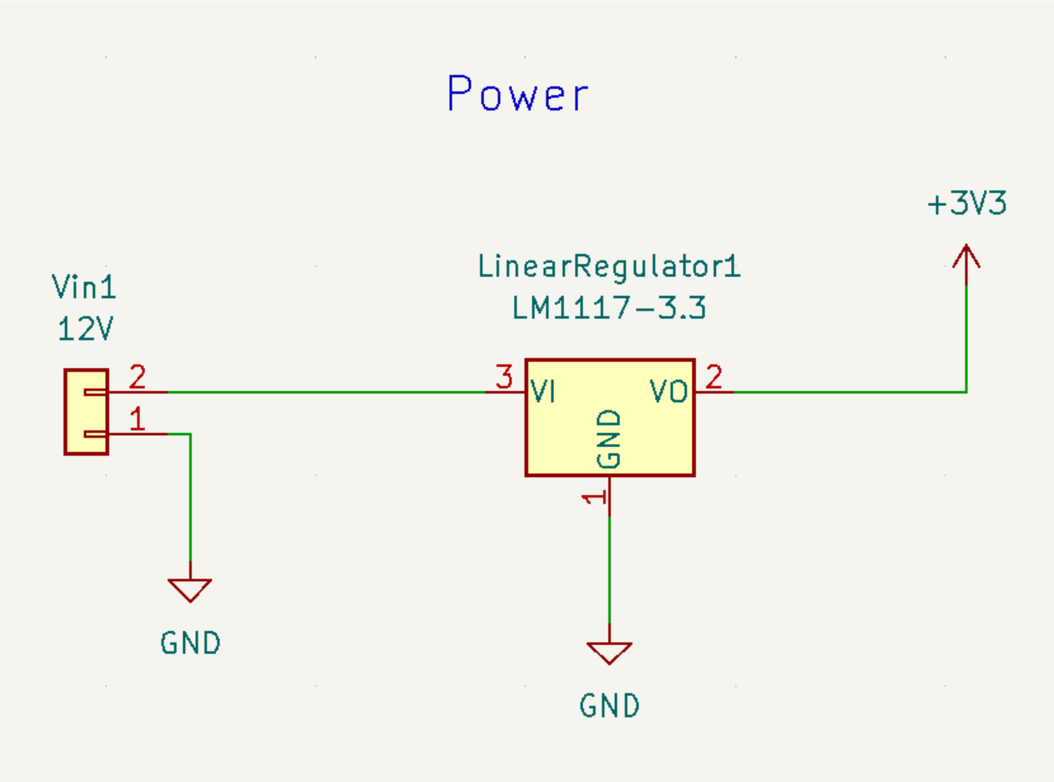

Figure 3. Schematic of power subsystem.

2.2.2 Sensor Subsystem

The Sensor Subsystem is responsible for detecting the ambient light level at the bottom of the net and converting it to a voltage output that is sent to the Control & Processing Subsystem. This subsystem consists of a photoresistor, which is part of a voltage divider circuit with a fixed 10 kΩ resistor, mounted on a small PCB at the bottom of the net. The schematic corresponding to this design can be seen in Figure 4. The photoresistor has a resistance of 2 kΩ at very high ambient light levels (~100 lux) and 100 kΩ at very low ambient light levels (~1 lux) according to its datasheet [7]. Utilizing the voltage divider equation below (1), we determined that the output voltage can take on any value between 0.3 V (at ~1 lux) and 2.75 V (at ~100 lux). A higher ambient light level indicates either a missed shot or an empty basket. In this case, the resistance of the photoresistor will be lower, and the output of the voltage divider circuit shown in Figure 4 will be closer to the maximum of 2.75 V. On the other hand, a lower ambient light level indicates a made shot. In this case, the resistance of the photoresistor will be higher, and the output of the voltage divider circuit will be closer to the minimum of 0.3 V.

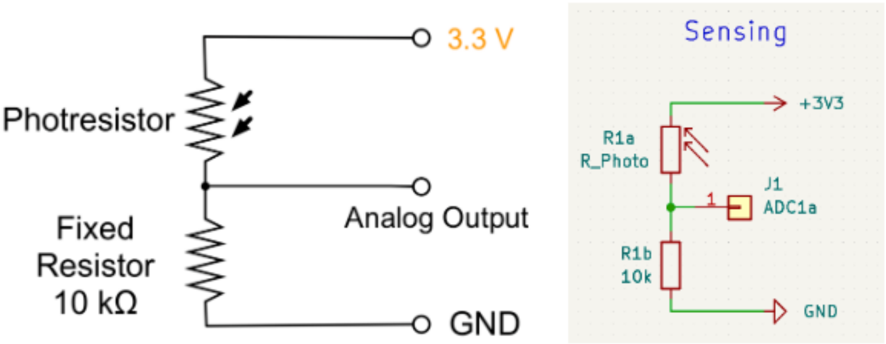

Figure 4. Sensor subsystem voltage divider circuit.

$$V_{OUT} = V_{DD} \cdot \left(\frac{R_{PHOTORESISTOR}}{R_{PHOTORESISTOR} + R_{FIXED}} \right) = 3.3 \cdot \left(\frac{R_{PHOTORESISTOR}}{R_{PHOTORESISTOR} + 10000} \right) \tag{1}$$

2.2.3 Control & Processing Subsystem

The Control & Processing Subsystem consists of two ATTiny45V microcontrollers: a "sensor microcontroller" and a "clock microcontroller". The sensor microcontroller is programmed to take an input voltage from the voltage divider circuit mentioned in the Sensor Subsystem, and determine whether a shot has been made. The clock microcontroller is programmed to run the game clock, stopping it when the sensor microcontroller determines that a shot has been made. The sensor microcontroller receives the voltage from the ambient light sensor circuit through pin ADC1 [8]. The microcontroller's internal architecture digitizes the input voltage to a 10-bit integer that is then compared to a calibrated threshold value between 0 and 1024 that is set in the program. This calibration is required due to the potentially differing ambient lighting conditions across the arenas in which the system could be used. If the input value is less than the threshold, then the sensor microcontroller determines that a shot has been made, and sends this information to the clock microcontroller. When the input value is greater than the threshold, the sensor microcontroller determines that the ball is not at the bottom of the basket, telling the clock microcontroller to keep the clock running. The sensor microcontroller communicates with the clock microcontroller through a 1-bit data signal that is sent from port PB1 on the sensor microcontroller and received by the port PB1 on the clock microcontroller [8]. The clock microcontroller is programmed to display a countdown timer, mimicking an NBA game clock. Descending values are written to the game clock display via I2C protocol using a loop with a constant delay of 0.1 seconds between iterations. When the clock microcontroller receives a high signal from the sensor microcontroller, indicating that a shot is made, it will break the aforementioned loop, which stops the clock.

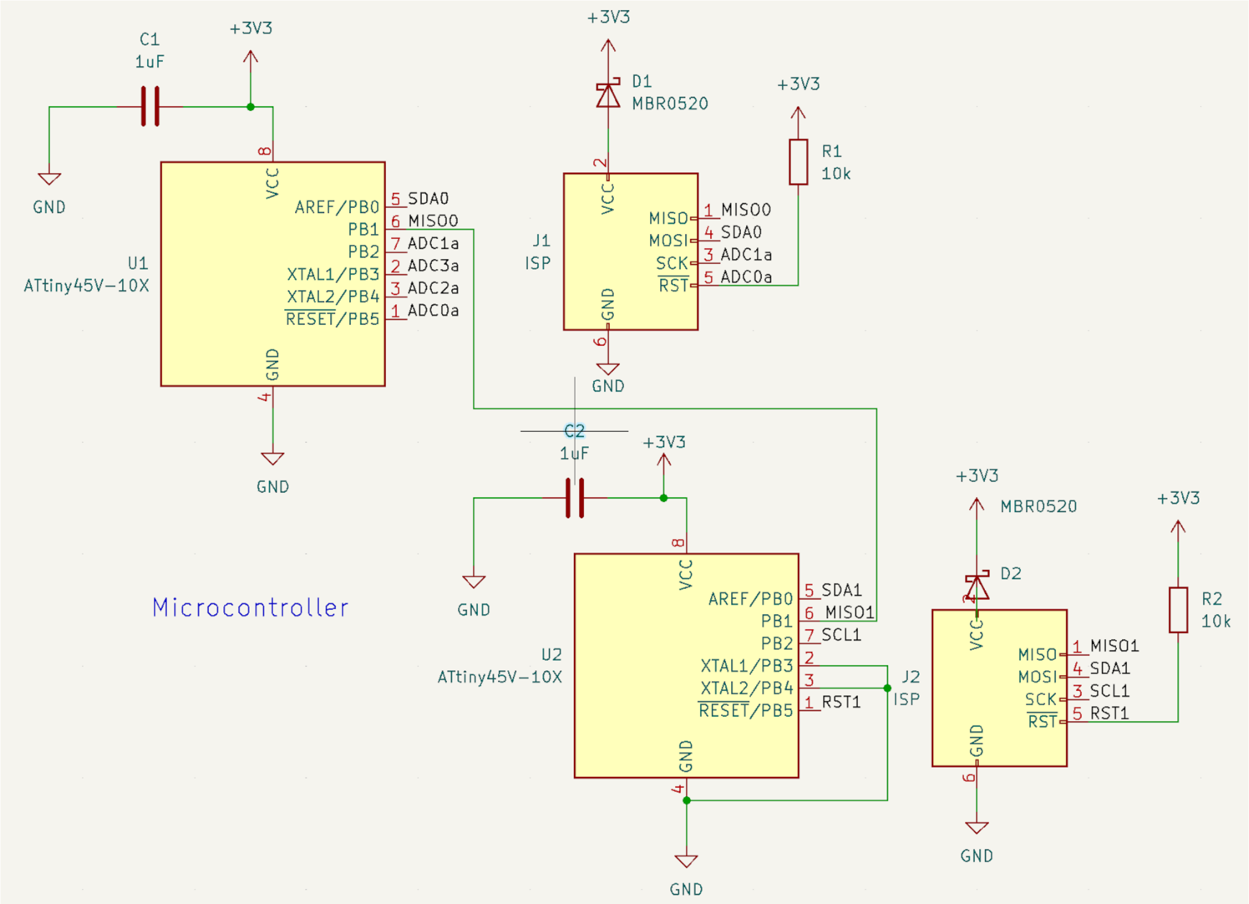

Figure 5. Schematic of Control & Processing Subsystem.

2.2.4 Clock Subsystem

The Clock Subsystem consists of a 4-digit 7-segment display with an I2C backpack converter [9]. The I2C backpack converter is a PCB that converts the I2C signal sent from the clock microcontroller to an array of traditional 7-segment display signals. Initially, we were considering only using a traditional 4-digit 7-segment display but determined that the limited number of outputs from the ATTiny45V microcontroller did not allow us to set each diode segment of every digit separately. To reduce the number of required outputs from the clock microcontroller, we reasoned that the use of only two outputs in I2C communication (SDA and SCL) would satisfy our requirements.

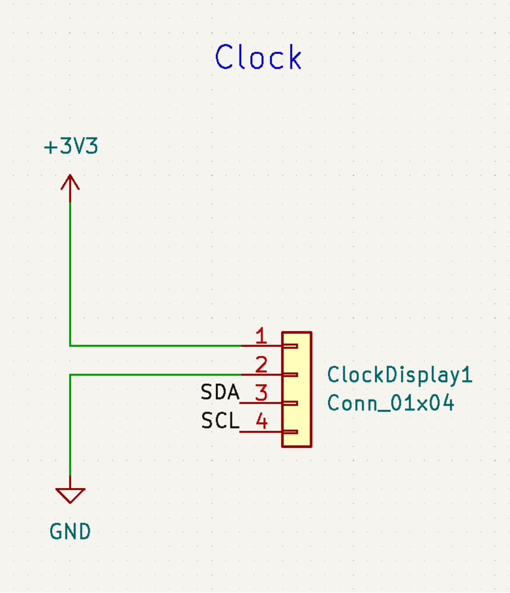

Figure 6. Schematic of Clock Subsystem.

3. Design Verification

3.1 Power Subsystem

As detailed in Table 11 in Appendix A, the requirements of the Power Subsystem specify the margin of error for the voltage output of the 12 V DC power supply, the voltage output of the 3.3 V linear regulator, and the quiescent current drawn by the system. Tables 1, 2and 3 below detail the results from the verification process for each requirement.

Table 1. Voltage Output of DC Power Supply (Req. 1)

Theoretical Voltage (V)	Measured Voltage (V)	Verified?
12	11.996	Yes

Table 2. Voltage Output of Linear Regulator Over 30 Seconds (Req. 2)

Timestamp (sec)	Theoretical Voltage (V)	Measured Voltage (V)	Verified?
0	3.30	3.296	Yes
10	3.30	3.287	Yes
20	3.30	3.292	Yes
30	3.30	3.295	Yes

Table 3. Quiescent Current Drawn for Low and High Ambient Light (Req. 2)

Ambient Light Level	Theoretical Current (mA)	Measured Current (mA)	Verified?
Low (~1 lux)	2.75	3.03	Yes
High (~100 lux)	442.75	437.22	Yes

3.2 Sensor Subsystem

As detailed in Table 12 in Appendix A, the requirements of the Sensor Subsystem specify that this subsystem must be able to detect the difference between an empty basket and the ball in the basket. We were able to verify all other subsystems before the sensor testing, so we determined that we could use the clock output to verify this requirement, as well as the high-level requirements for the whole system. Tables 4 and 5 below detail the results from the verification process for each requirement.

Table 4. Clock and Sensor Output on Made Shots from 18° Increments with Threshold of 1.65 V (Req. 1)

Position of Shot (°)	Sensor Voltage Output (V)	Clock Output	Verified?
0	1.243	Stops	Yes
18	0.984	Stops	Yes
36	0.865	Stops	Yes
54	0.844	Stops	Yes
72	1.140	Stops	Yes
90	1.321	Stops	Yes
108	0.994	Stops	Yes
126	1.012	Stops	Yes
144	0.869	Stops	Yes
162	1.042	Stops	Yes
180	1.003	Stops	Yes

Table 5. Clock and Sensor Output on Missed Shots from 18° Increments with Threshold of 1.65 V (Req. 1)

Position of Shot (°)	Sensor Voltage Output (V)	Clock Output	Verified?
0	1.888	Running	Yes
18	1.936	Running	Yes
36	2.342	Running	Yes
54	2.270	Running	Yes
72	2.242	Running	Yes
90	2.045	Running	Yes
108	3.036	Running	Yes

126	1.978	Running	Yes
144	2.784	Running	Yes
162	2.132	Running	Yes
180	2.457	Running	Yes

3.3 Control & Processing Subsystem

As detailed in Table 13 in Appendix A, the requirements of the Control & Processing Subsystem specify that the data signal output from the sensor microcontroller must be high when the sensor is triggered in a fashion that indicates a made shot and must be low when the sensor output does not indicate that a shot is made. Furthermore, the signal input at pin PB1 of the clock microcontroller must be a logical high when the output of the sensor microcontroller is a logical high, and vice versa. Tables 6 and 7 below detail the results from the verification process for each requirement.

Table 6. Sensor Microcontroller PB1 Voltage Output for Threshold of 1.65 V (Req. 1)

Input Voltage to ADC Pin (V)	Expected Voltage Output (V)	Measured Voltage Output (V)	Verified?
0	2.4 - 3.3	3.265	Yes
0.5	2.4 - 3.3	3.277	Yes
2.4	0 - 0.5	0.122	Yes
3.3	0 - 0.5	0.131	Yes

Table 7. Clock Microcontroller Voltage at Pin PB1 (Req. 2)

Logical Output of Pin PB1 of Sensor Microcontroller	Expected Voltage at Pin PB1 of Clock Microcontroller (V)	Measured Voltage at Pin PB1 of Clock Microcontroller (V)	Verified?
Low	0 - 0.5	0.118	Yes
High	2.4 - 3.3	3.267	Yes

3.4 Clock Subsystem

As detailed in Table 14 in Appendix A, the requirements of the Clock Subsystem specify that the displayed clock value must mimic a running timer when the Control & Processing Subsystem determines that a shot is not made, the displayed clock value must stop changing when the Control & Processing Subsystem determines that a shot is made, and the clock must stop within 0.3 seconds of a made shot. Table 8 below details the results from the verification process for each requirement.

Table 8. Clock Output for ADC Input Threshold of 1.65V (Req. 1, 2, 3)

Input Voltage to ADC Pin (V)	Expected Clock Output	Observed Clock Output	Verified?
0	Stops within 0.3s	Stops within 0.1s	Yes
0.5	Stops within 0.3s	Stops within 0.1s	Yes
2.4	Running	Running	Yes
3.3	Running	Running	Yes

4. Cost & Schedule

4.1 Parts

Table 9. Cost of all Parts.

Description	Manufacturer	Part #	Quantity	Cost (per unit)
DC Power Supply	Gravitech	12V1A-25-POS-WALL	1	$8.69
Linear Voltage Regulator	Texas Instrument	LM117H	1	$10.24
Microcontroller	Microchip Technology	ATTINY45V-10XU	2	$1.89
4 digit 7-segment Display	Adafruit	879	1	$9.95
Total for Required Parts in Final Design				$32.66
Ambient Light Sensor	Lite-On Inc.	LTR-329ALS-01	10	$0.88
Spare Microcontroller	Microchip Technology	ATTINY45V-10XU	1	$1.89
Spare Linear Voltage Regulator	Texas Instrument	LM117H	1	$10.24
I2C Multiplexer	Adafruit	TCA9548A	1	$6.95
Mini Hoop [10]	Sklz	088-08-0037	1	$29.99
Total for All Parts Used Throughout Design Process				$82.61

4.2 Labor

$39.86/person/hour x 3 people x 10 hours worked/week * 13 weeks worked = $15,545.40 Total [11].

4.3 Schedule

Table 10. Individual Work Schedules.

Week	Work	Pranav	Rahul	Saud
1	Submit RFA	Brainstorm Idea, Create RFA with Rahul and Saud	Brainstorm Idea, Create RFA with Pranav and Saud	Brainstorm Idea, Create RFA with Rahul and Pranav
2	Submit Project Proposal and Talk to Machine Shop	Meet with Akshat, meet with machine shop, research sensors to use, and create project proposal with Rahul and Saud	Meet with Akshat, meet with machine shop, research sensors to use, and create project proposal with Pranav and Saud	Meet with Akshat, meet with machine shop, research sensors to use, and create project proposal with Rahul and Pranav

3	Work on Design Document	Work on introduction, power subsystem, sensor subsystem, cost analysis, schedule and citations	Work on introduction, sensor subsystem, microcontroller subsystem, tolerance analysis and citations	Work on block diagram, physical design, clock subsystem, ethics, and citations
4	Submit Design Document and Order Parts	Revise clock subsystem, microcontroller subsystem, and tolerance analysis, and citations. Work with Rahul and Saud to order parts.	Revise block diagram, physical design, clock subsystem, ethics, and citations. Work with Pranav and Saud to order parts.	Revise introduction, power subsystem, sensor subsystem, cost analysis, schedule and citations.Work with Rahul and Pranav to order parts.
5	Finalize PCB Layout and Order PCB	Ensure that the schematic matches the PCB layout. Order PCB.	Check PCB layout for trace bend angles, mounting hole locations, ground planes, stitching vias. Make sure reasonable part sizes are chosen for PCB.	Check PCB layout for connectors for all incoming and outgoing connections, thicker traces for power delivery, labeling on silkscreen layers and extra pins for debugging.
6	Build and Test Power Subsystem, Complete Teamwork Evaluation and visit Machine Shop	Build the linear voltage regulator with Rahul and Saud, and test using an oscilloscope. Complete teamwork evaluation and visit machine shop with Rahul and Saud.	Build the linear voltage regulator with Pranav and Saud, and test using an oscilloscope. Complete teamwork evaluation and visit machine shop with Pranav and Saud.	Build the linear voltage regulator with Rahul and Pranav, and test using an oscilloscope. . Complete teamwork evaluation and visit machine shop with Rahul and Pranav.
7	Solder all Components to PCB and Complete Individual Progress Reports	Solder microcontroller and connections from power subsystem and complete individual progress report.	Solder connections from ambient light sensor and complete individual progress report.	Solder connections from game clock display and complete individual progress report.
8	Test and Debug Overall System	Perform unit tests, test all cases and make necessary adjustments with Rahul and Saud.	Perform unit tests, test all cases and make necessary adjustments with Pranav and Saud.	Perform unit tests, test all cases and make necessary adjustments with Rahul and Pranav.
9				

10	Continue Testing, Prepare for Mock Demo, and Start Final Paper.	Continue making adjustments based on test results. Start final paper introduction.	Continue making adjustments based on test results. Work on final paper design procedure with Saud.	Continue making adjustments based on test results. Work on final paper design procedure with Rahul.
11	Mock Demo, Prepare for Final Demo, and Continue Working on Final Paper	Bring all hardware to TA for Mock Demo. Make necessary additions and adjustments for final demo. Start final paper verification with Rahul.	Bring all hardware to TA for Mock Demo. Make necessary additions and adjustments for final demo. Start final paper verification with Pranav.	Bring all hardware to TA for Mock Demo. Make necessary additions and adjustments for final demo. Start final paper design details.
12	Final Demo, Prepare for Presentation, Continue Working on Final Paper	Bring all hardware to Final Demo. Make script for final presentation. Start final paper costs and conclusions sections with Rahul and Saud.	Bring all hardware to Final Demo. Make script for final presentation. Start final paper costs section and conclusions sections with Pranav and Saud.	Bring all hardware to Final Demo. Make script for final presentation. Start final paper costs and conclusions sections with Rahul and Pranav.
13	Submit Final Paper, Notebook, and Team Evaluations	Complete references section for final paper. Revise entire paper with Rahul and Saud. Submit notebook and complete team evaluations.	Complete references section for final paper. Revise entire paper with Pranav and Saud. Submit notebook and complete team evaluations.	Complete references section for final paper. Revise entire paper with Rahul and Pranav. Submit notebook and complete team evaluations.

* From Week 5 - 12, Pranav supervised all of Rahul's responsibilities, Rahul supervised all of Saud’s responsibilities, and Saud supervised all of Pranav’s responsibilities.

5. Conclusion

5.1 Accomplishments

By the end of the project, we were able to successfully verify every subsystem, as outlined within our Design Verification section, as well as all high-level requirements. We were successful in ensuring that the delay between a made shot and the clock stoppage is less than 0.1 seconds, which we tested through recording slow motion footage of the system. Additionally, we achieved over 90% accuracy for classification of the shots that were attempted.

5.2 Uncertainties

Although our system achieves over 90% accuracy when classifying shots as “made” or “missed” based on the ambient light level, the primary concern associated with our solution is the degree of accuracy due to the strict standards of the NBA. In order for our system to be ready for implementation in an NBA arena, we would need to prove that we can achieve over 98% accuracy with a sample size of over 10,000 shots at recreational levels of basketball. The results of this experiment may require us to modify our implementation. Furthermore, the results of our system are very sensitive to fluctuations in the lighting of the environment. Events such as a light being turned off or a cloud covering the sunlight from a window would require recalibration of the sensor. However, we believe that an NBA arena would provide a consistent lighting environment for the duration of the game, so this concern could be alleviated.

5.3 Ethical considerations

As engineers, we have an obligation to ensure that our products and building practices adhere to the IEEE Code of Ethics. Although our product does not pose any significant safety issues, we have to account for other ethical standards. Specifically, our device cannot be tampered with to unfairly benefit one party, in accordance with standard I.4 in the IEEE Code of Ethics. Additionally, we will seek and accept criticism of our technical work and make realistic claims based on the data we collect through extensive testing, in accordance with standard I.5. Moreover, we will design an enclosure for our PCBs with the game clock such that we avoid injuring players, in accordance with standard II.9. This standard also applies to the installation of the system on a full-size basketball court. Finally, we will hold each other accountable to always adhere to the IEEE Code of Ethics, including the entire design and build process as well as after we present our finished product, as stated in standard III.10. [12]

In addition to the IEEE Code of Ethics, we will design our product to be compatible with NBA league regulations and ensure that its implementation does not disturb the spirit of the game. As such, our system must be consistent in average time delay and accuracy between the two hoops on the basketball court. Furthermore, any given device has to have a consistent delay in stopping the game clock. Moreover, the system must not significantly disturb the flow of the shot and must adhere to NBA league regulations regarding equipment. Along with the IEEE Code of Ethics, this ensures that we uphold the highest ethical standards.

5.4 Future work

Much of the future improvements involve cohesion with the operation of the game clock. This would include the ability for the game clock operator to resume the clock upon inbounding of the ball, which occurs after every made shot. Also, the game clock operator would be given the option to override the displayed clock value in the case that a player steps out of bounds, commits a foul, or the system malfunctions. Moreover, we would implement automatic detection to determine if the game is in the last two minutes, so that the system would not have to be manually turned on at that time. Along with this, we would like to create a second system to simulate real game clock management and ensure that both systems are working identically and without conflict.

References

[1] NBA. “Ray Allen's AMAZING game-tying 3-pointer in Game 6!,” *Youtube*, June 18, 2018. [Video file]. Available: https://youtu.be/tr6XsZVb-ZE. [Accessed: 04-May-2022].

[2] House of Highlights. “DRAMATIC Last 2 Minutes of Game 4 - Suns vs Bucks - 2021 NBA Finals,” *Youtube*, July 14, 2021. [Video file]. Available: https://youtu.be/5TnDxmVLfis. [Accessed: 04-May-2022].

[3] W. H. McKernan, “Who's Trent Tucker?,” *IAABO*. [Online]. Available: https://iaabo.org/WTT_Part3.pdf. [Accessed: 04-May-2022].

[4] “Rule no. 5: Scoring and timing,” *NBA Official*. [Online]. Available: https://official.nba.com/rule-no-5-scoring-and-timing/. [Accessed: 04-May-2022].

[5] “12V1A-25-POS-WALL Gravitech: Mouser,” *Mouser Electronics*. [Online]. Available: https://www.mouser.com/ProductDetail/Gravitech/12V1A-25-POS-WALL?qs=Vxac6xGyzPnrevPKUBfxAw%3D%3D. [Accessed: 04-May-2022].

[6] “LM117,” *LM117 data sheet, product information and support*. [Online]. Available: https://www.ti.com/product/LM117. [Accessed: 04-May-2022].

[7] “GL5528,” *CdS Photoconductive Cells GL5528*. [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/LightImaging/SEN-09088.pdf. [Accessed: 05-May-2022].

[8] Atmel, “ATtiny25/V / ATtiny45/V / ATtiny85/V,” ATtiny25/V / ATtiny45/V / ATtiny85/V datasheet, Aug 2013. Available: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-2586-AVR-8-bit-Microcontroller-ATtiny25-ATtiny45-ATtiny85_Datasheet.pdf

[9] Kingbright, “Three Digit Numeric Display,” BC56-12SRWA datasheet, Feb. 2020. Available: https://www.kingbrightusa.com/images/catalog/SPEC/BC56-12SRWA.pdf

[10] “Sklz Pro Mini Hoop - black/gray,” *Target*. [Online]. Available: https://www.target.com/p/sklz-pro-mini-hoop-black-gray/-/A-54554072#lnk=sametab. [Accessed: 04-May-2022].

[11] “Salary Averages,” *Electrical & Computer Engineering | UIUC*. [Online]. Available: https://ece.illinois.edu/admissions/why-ece/salary-averages. [Accessed: 04-May-2022].

[12] IEEE, “IEEE Code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 04-May-2022].

Appendix A Requirements and Verification Tables

Table 11. Power Subsystem Requirements and Verification

Requirement	Verification	Verification Status (Y or N)
1. The DC power supply must provide a constant 12 V within a 10% margin of error.	1A. Measure the output voltage of the DC power supply using a multimeter to ensure that the voltage of the DC power supply is between 10.8 and 13.2 V.	Y
2. The output voltage of the 12-to-3.3V linear regulator must be 2.7 to 3.6 V with an output current of 2.75 to 442.75 mA as specified by the datasheets for the microcontrollers and game clock.	2A. Measure the output voltage of the 12-to-3.3V linear regulator using a multimeter to ensure that the voltage is between 2.7 and 3.6 V. 2B. Measure the output current of the 12-to-3.3V linear regulator using a multimeter and a 1 ohm resistor in series with the relevant circuitry to ensure that the current is between 2.75 and 442.75 mA.	Y

Table 12. Sensor Subsystem Requirements and Verification

Requirements	Verification	Verification Status (Y or N)
1. The subsystem must be able to detect the difference between an empty basket and the ball in the basket.	1A. Using the multimeter, measure and display the output from the sensor when the basket is empty as a result of a missed shot. This will be done by rolling the ball on a handheld ramp 10 times at 18-degree increments such that the ball drops 1 inch outside the rim. 1B. Using the multimeter, measure the voltage output from the sensor when the ball is in the net. This will be done by rolling the ball on a handheld ramp 10 times at 18-degree increments into the net. 1C. Ensure that the range of output values in 1A does not overlap with the range of output values in 1B.	Y

Table 13. Control & Processing Subsystem Requirements and Verification

Requirements	Verification	Verification Status (Y or N)
1. The data signal output from the sensor microcontroller must be high when the sensor is triggered in a fashion that indicates a made shot, and must be low when the sensor does not indicate that a shot is made.	1A. In the case where the sensor is not triggered, the microcontroller should output a low voltage indicating a shot is not made. This will be seen by a multimeter reading less than 0.5 V at the output pin. 1B. In the case the sensor is triggered, the microcontroller should output a high voltage indicating a shot is made. This will be seen by a multimeter reading greater than 2.4 V at the output pin. 1C. If cases 1A and 1B are satisfied, or if the multimeter reads greater than 2.4V when the ball passes through the net and reads less than 0.5V when the ball is not passing through the net, then the requirement is met.	Y
1. The signal input at pin PB1 of the clock microcontroller must be a logical high when the output of the sensor microcontroller is a logical high, and must be a logical low when the output of the sensor microcontroller is a logical low.	2A. Set the pin PB1 output of the sensor microcontroller to a logical high. Using a multimeter, measure the voltage at the clock microcontroller's input (pin PB1). The multimeter must display between 2.4 V and 3.3 V. 2B. Set the pin PB1 output of the sensor microcontroller to a logical low. Using a multimeter, measure the voltage at the clock microcontroller's input (pin PB1). The multimeter must display between 0 V and 0.5 V. 2C. If cases 2A and 2B are satisfied, then this requirement is met.	Y

Table 14. Control & Processing Subsystem Requirements and Verification

Requirements	Verification	Verification Status (Y or N)
1. The displayed clock value must decrease, mimicking a timer or game clock, when the control & processing subsystem determines that a shot is not made.	1A. Use a DC power supply to set the PB1 pin of the clock microcontroller to 0V or use the connection from the PB1 output of the sensor microcontroller (if it is working) when the ball does not pass through the net. 1B. Check the value displayed on the game clock to ensure it is decreasing in a fashion that mimics a timer.	Y
1. The displayed clock value must stop changing when the control & processing subsystem determines that a shot is made.	2A. Follow steps 1A and 1B. 2B. Use a DC power supply to set the PB1 pin of the clock microcontroller to 3.3V or use the connection from the PB1 output of the sensor microcontroller (if it is working) when the ball is passing through the net. 2C. Check the value displayed on the game clock to ensure it stops as the ball passes through the net.	Y
1. The displayed clock value must stop within 0.3 seconds of a made shot.	3A. Follow steps 1A and 1B. 3B. Set up a camera that will record a shot and the clock display in slow motion. 3C. Follow step 2B. 3D. Analyze the recording to verify that the clock display stopped within 0.3 seconds of clearing the net.	Y