ECE 445

04/25/2022

Design Document

Automated NBA Game Clock Stopper

Team Number: 36

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Problem and Solution Overview

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]. Although this may seem insignificant, this is a large amount of time in the final seconds of a game. 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]. An accurate stoppage of the clock is crucial for close games as every tenth of a second is enough time for another possession, which can influence the outcome of the game. We are proposing the development of a system that will track when the ball goes through the hoop and subsequently stops the game clock. This will be done using a five-sensor system that will be integrated with the net to minimize inaccurate clock stoppage.

We plan to use four ambient light sensors that will be placed on the net five inches below the rim. This measurement is because the ball will be halfway down the rim with minimal chance to bounce out. These sensors will be placed circularly around the center of the net at 90-degree increments. We will have a fifth ambient light sensor that will be 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 will be used to stop the game clock at the correct time [3]. All five sensors will connect to the PCB, constantly outputting signals that indicate the level of ambient light. Our PCB will then determine if the clock needs to be stopped and send an appropriate signal to stop the clock when a shot is made.

Visual Aid

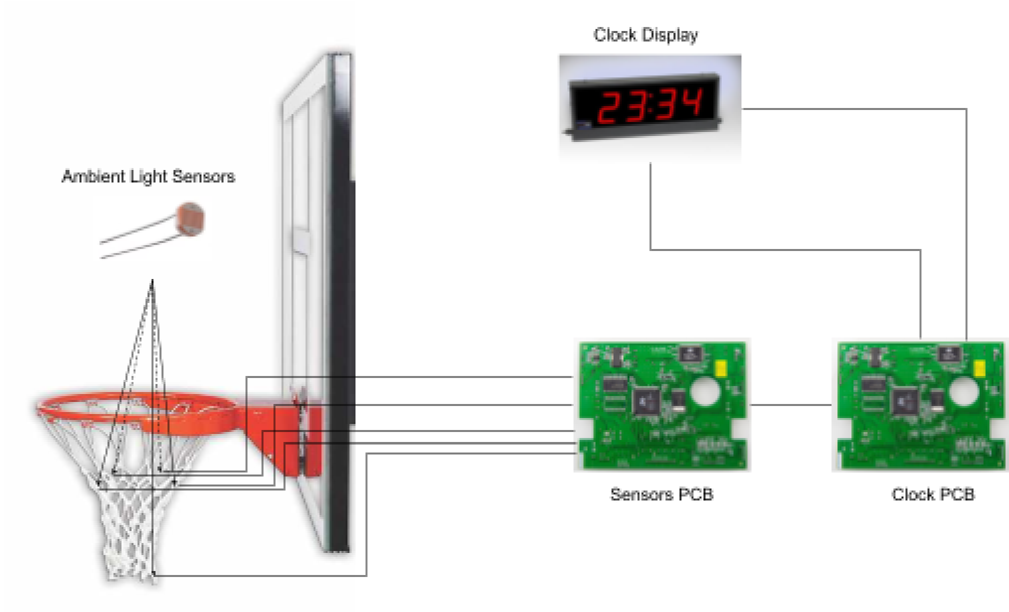

Figure 1. Visual aid of proposed system.

High-level Requirements List

- The system must not stop the clock in the situation where a human hand is touching the net at the horizontal level of the four upper sensors.
- The clock must stop within 0.3 seconds of the basketball being detected by the bottom sensor on a made shot.
- In the case where the basketball hits the net without going through the rim, causing the net to sway or fold, the system must not stop the clock.

Block Diagram

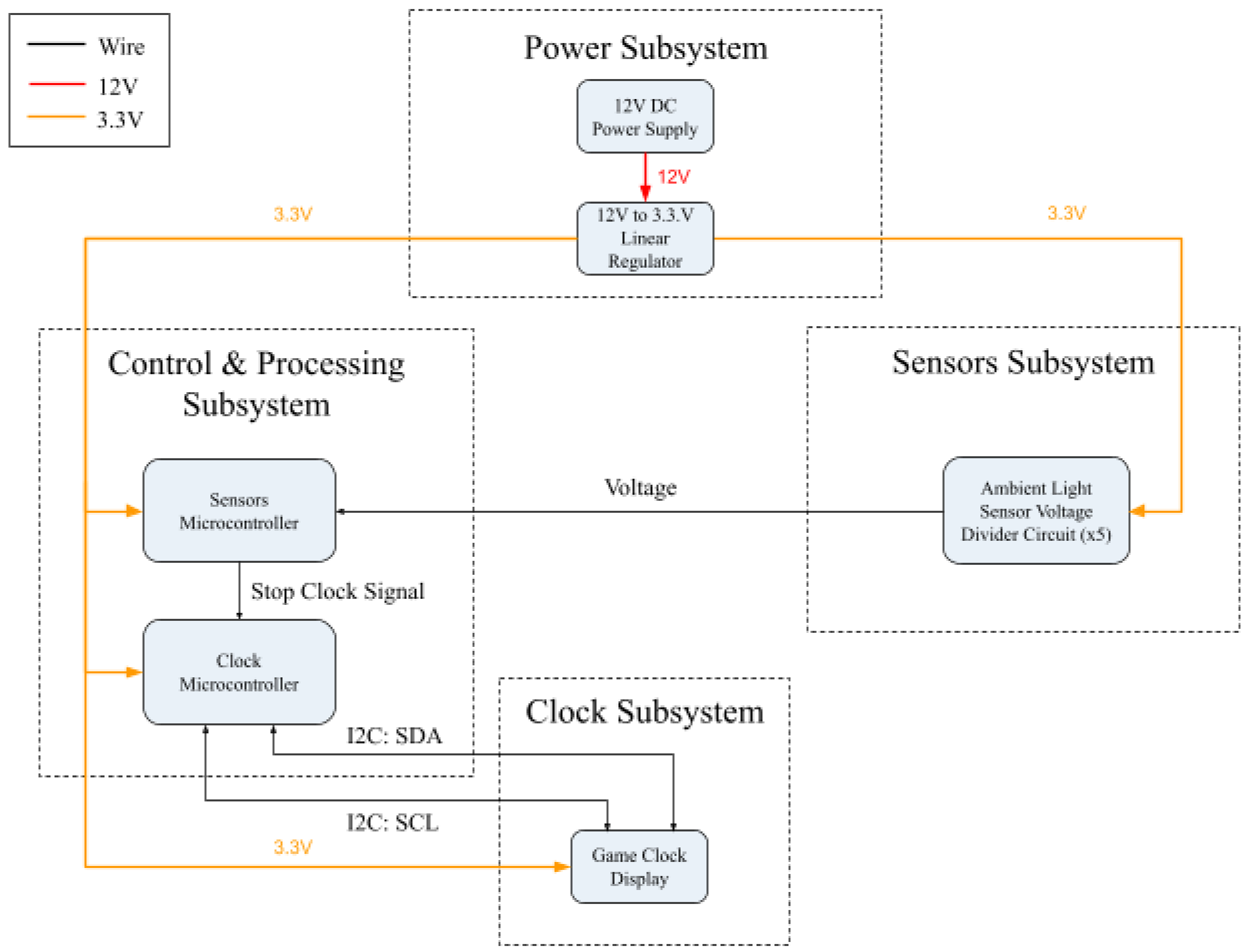

Figure 2. Block diagram breakdown of subsystems.

The block diagram consists of four subsystems: power, sensor, control & processing, and clock. The power subsystem will provide the appropriate power to each component in the system. The sensor subsystem is responsible for communicating the signals from each of the five sensors to the control & processing subsystem. The control & processing subsystem is responsible for utilizing two PCBs with microcontrollers that take the signals from the sensors and determine that a shot has been made when at least two of the four top sensors and the bottom sensor are triggered. The clock subsystem takes this decision and its microcontroller stops the timer, which is reflected on the game clock display.

Physical Design

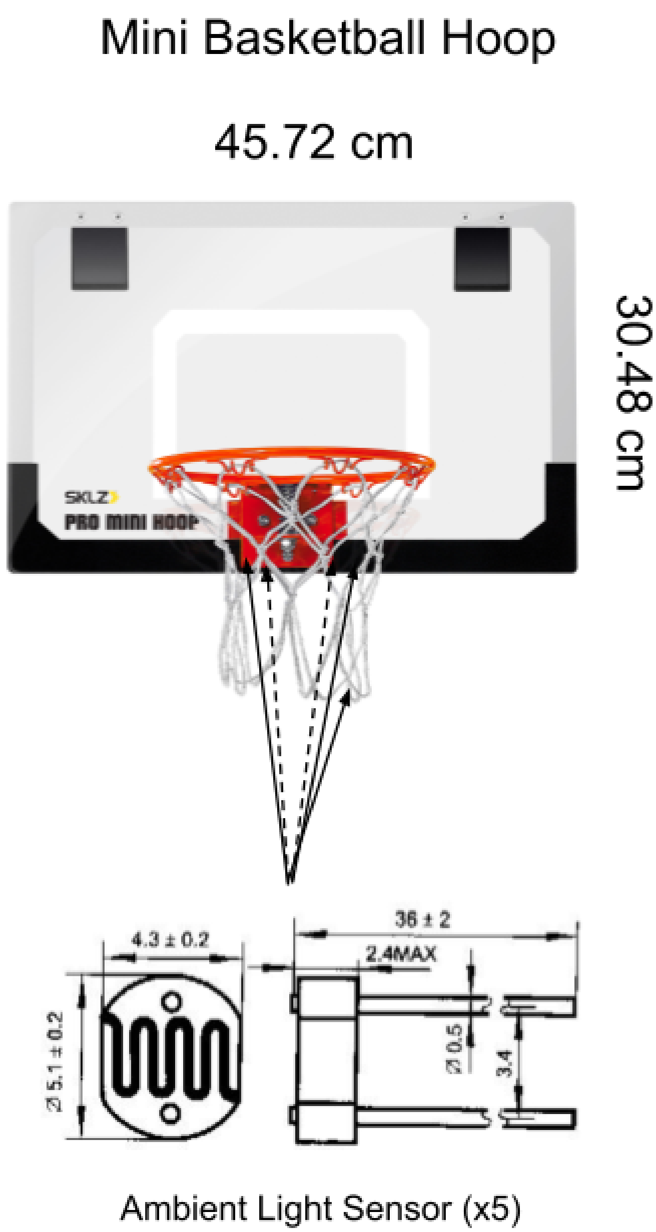

Figure 3. Physical design measurements of proposed system components. Note that ambient light sensor dimensions are in millimeters.

Power Subsystem

The power subsystem is responsible for delivering power to the microcontrollers, clock display, and all five ambient light sensors. As such, it connects to each of the other subsystems to provide power to their components as indicated by the orange arrows in the block diagram. We plan to use a 12V DC power supply along with a 12V-to-3.3V linear regulator to step down the DC voltage to an acceptable level for the components based on their datasheets.

The power supply, with a built-in voltage regulator, will be connected to a wall outlet and have 12V of available voltage for all components of the system. This power supply should be able to supply between 2.75 to 442.75 mA to the rest of the system continuously [4][5].

Requirements	Verification
1. The DC power supply must provide a constant 12 V within a 10% margin of error. 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.	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. 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.

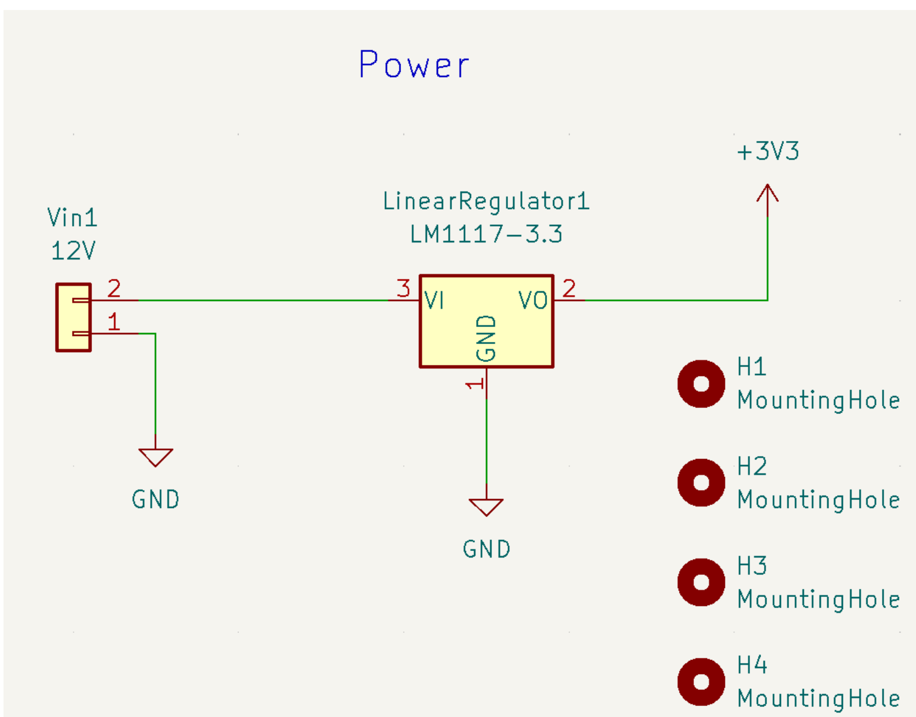

Figure 4a. Schematic of power subsystem.

Sensors Subsystem

The sensor subsystem contains five ambient light sensors that are implemented by five photoresistors in series with five separate fixed resistors, forming five voltage divider circuits. The sensors are powered by the power subsystem, with one terminal of each photoresistor connecting to the 3.3V power line. The voltage outputs of these sensors, which are measured at the nodes that connect each photoresistor with its fixed resistor, will act as inputs for our control & processing subsystem. The signals from these sensors will be used to determine a made shot and as a result trigger the sequence to stop the clock [6].

Requirements	Verification
1. The subsystem must be able to detect the difference between an empty basket and the ball in the basket. The difference in the resulting output values are determined from testing as mentioned in the tolerance analysis. 2. The subsystem must be able to detect the difference between a ball hitting the bottom of the net and a ball being held directly above the net such that a shadow is cast over the sensors. The difference in the resulting output values are determined from testing as mentioned in the tolerance analysis.	1A. Using the sensors microcontroller, measure and display the output from the sensors of an empty basket. 1B. Using the sensors microcontroller, measure the highest difference in the output from the sensors 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. Compare the difference in the output values between 1B and 1A, it should be consistent with the results of the tolerance analysis. 2A. Using the sensors microcontroller, measure the output of the ambient light sensor when the ball is held at the bottom of the net. 2B. Using the sensors microcontroller, measure the output when the ball is held directly above the net. 2C. Compare the difference in output values between 2B and 2A; it should be consistent with the results of the tolerance analysis.

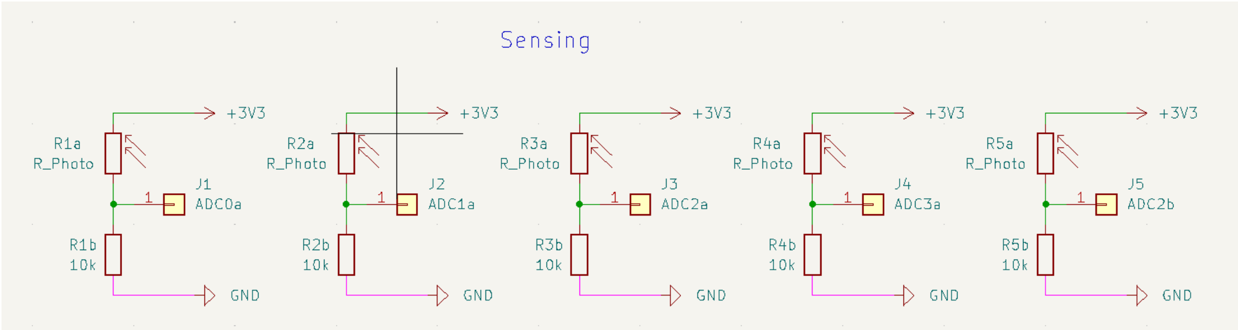

Figure 4b. Schematic of sensors subsystem.

Control & Processing Subsystem

The control & processing subsystem contains the two microcontrollers, which are powered by the power subsystem. The five nodes that connect the photoresistors to the fixed resistors connect to five ADC pins on the "sensors microcontroller". The program on the sensors microcontroller will determine if a shot is made based on the ambient light values detected by the sensors. We will be using an ATTiny45 microcontroller soldered onto our PCB to process the output signals from the ambient light sensors. The sensors microcontroller will implement the required logic to convert these five inputs into a signal that indicates when a shot is made. If at least two of the four upper sensors are triggered as described in the tolerance analysis, then the ball is known to be in the basket. The microcontroller will then "look" for the bottom sensor to be triggered in order to know when a shot is made. If the sensors microcontroller determines that a shot has been made, it will send a logical high to the "clock microcontroller". Otherwise, it will send a logical low.

The clock microcontroller is responsible for reading the output from the sensors microcontroller to know when a shot has been made and send an I2C signal to stop the clock accordingly. The program runs a game clock by outputting decreasing numbers to the display, with 0.1 seconds between each displayed number. When a shot is made, this loop will be broken and the current number will stay displayed. Without the sensors and clock microcontrollers, we would not be able to determine when a shot is made and send a signal to stop the clock.

Requirements	Verification
1. The data signal output from the sensors microcontroller must be high when the sensors are triggered in a fashion that indicates a made shot, and must be low when the sensors do not indicate that a shot is made.	1A. In the case where only the bottom sensor is 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 where none of the five sensors

2. The signal input at pin PB1 of the clock microcontroller must be a logical high when the output of the sensors microcontroller is a logical high, and must be a logical low when the output of the sensors microcontroller is a logical low.	are 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. 1C. In the case when one top sensor and the bottom sensor are triggered, the microcontroller should output a low voltage indicating the shot is not made. This will be tested four times to account for each of the four top sensors being triggered along with the bottom sensor. This will be seen by a multimeter reading less than 0.5 V at the output pin. 1D. In the case when two of the top sensors and the bottom sensor are triggered, the microcontroller should output a high voltage indicating the shot is made. This will be tested six times to account for each combination of two of the four top sensors being triggered along with the bottom sensor. This will be seen by a multimeter reading greater than 2.4 V at the output pin. 1E. In the case when three of the top sensors and the bottom sensor are triggered, the microcontroller should output a high voltage indicating the shot is made. This will be tested four times to account for each combination of two of the four top sensors being triggered along with the bottom sensor. This will be seen by a multimeter reading greater than 2.4 V at the output pin. 1F. In the case when all of the sensors are triggered, the microcontroller should output a high voltage indicating the shot is made. This will be seen by a multimeter reading greater than 2.4 V at the output pin. 1G. If all cases 1A-1F 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.

	2A. Set the pin PB1 output of the sensors microcontroller to a logical high. Read and display the value at the clock microcontroller’s input (pin PB1) on the serial monitor. The serial monitor must display a logical high. 2B. Set the pin PB1 output of the sensors microcontroller to a logical low. Read and display the value at the clock microcontroller’s input (pin PB1) on the serial monitor. The serial monitor must display a logical low. 2C. If cases 2A and 2B are satisfied, then this requirement is met.

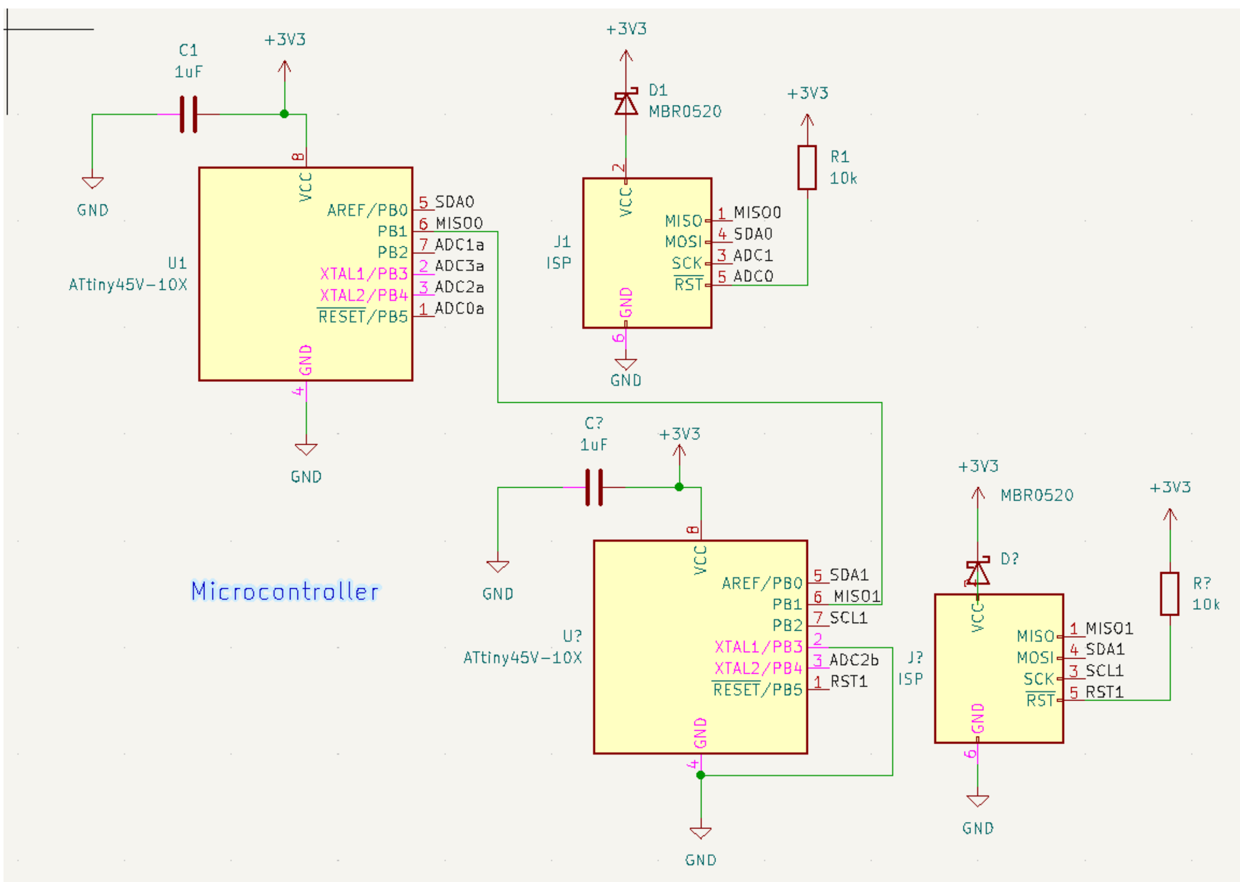

Figure 4c. Schematic of control & processing subsystem.

Clock Subsystem

The clock subsystem consists of the clock microcontroller connected to a clock display. The clock microcontroller will run the clock and display the current clock value on the clock display until the sensors microcontroller determines that a shot has been made, at which point the displayed time will stop decreasing, which will be reflected on the clock display. The clock display receives power from the power subsystem and clock data from the clock microcontroller's SDA and SCL lines, which are converted to traditional seven-segment display signals through an I2C backpack, which will convert the I2C signal into separate signals for each of the diodes in the 4-digit 7-segment display. The display will show the amount of time left accurate to within a tenth of a second [8].

Requirements	Verification
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. 2. The displayed clock value must stop changing when the control & processing subsystem determines that a shot is made. 3. The displayed clock value must stop within 0.3 seconds of a made shot.	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 sensors 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. 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 sensors 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. 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.

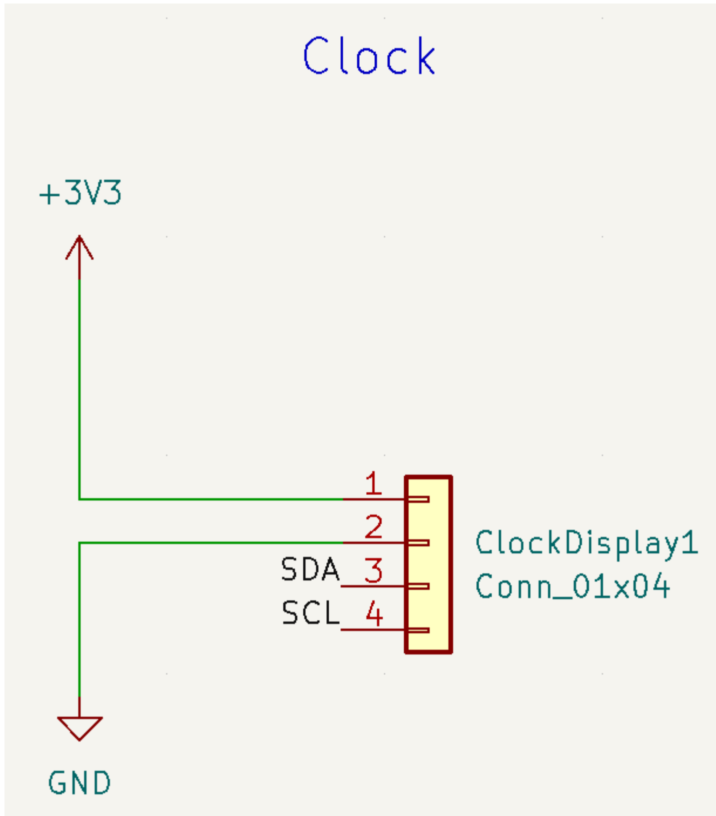

Figure 4d. Schematic of clock subsystem.

Tolerance Analysis

The interface critical to the success of our project that poses the most challenging requirement is the detection of a made shot. As mentioned in the sensors subsystem section, a shot is considered made when at least two of the four upper ambient light sensors are triggered along with the lower sensor. We decided to consider at least two of the four sensors triggering to be a “made” shot because of shots like in figure 5. In this example, the ball is coming toward the camera and is pressing against the net. We see that ambient light sensors 1 and 4 would be triggered, but sensors 2 and 3 may not. Therefore, since the minimum number of upper sensors that can be triggered for a made shot is two, we desire at least two upper sensors to be triggered to consider a made shot.

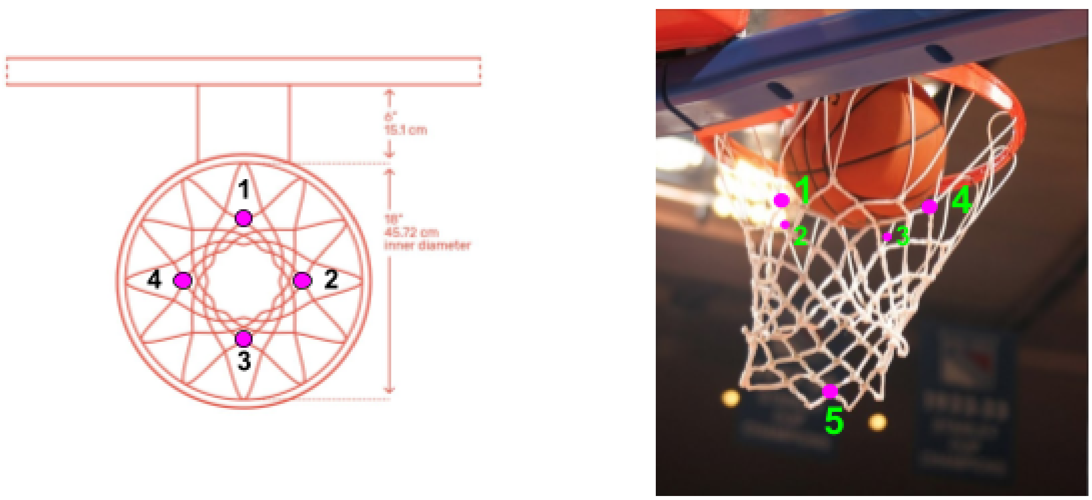

Figure 5. Sensor placement (left). Angled basketball shot traveling in towards the camera (right).

Sensor #1	Sensor #2	Sensor #3	Sensor #4	Sensor #5	Output
0	0	0	0	0	0
0	0	0	0	1	0
0	0	0	1	0	0
0	0	0	1	1	0
0	0	1	0	0	0
0	0	1	0	1	0
0	0	1	1	0	0
0	0	1	1	1	1

0	1	0	0	0	0
0	1	0	0	1	0
0	1	0	1	0	0
0	1	0	1	1	1
0	1	1	0	0	0
0	1	1	0	1	1
0	1	1	1	0	0
0	1	1	1	1	1
1	0	0	0	0	0
1	0	0	0	1	0
1	0	0	1	0	0
1	0	0	1	1	1
1	0	1	0	0	0
1	0	1	0	1	1
1	0	1	1	0	0
1	0	1	1	1	1
1	1	0	0	0	0
1	1	0	0	1	1
1	1	0	1	0	0
1	1	0	1	1	1
1	1	1	0	0	0
1	1	1	0	1	1
1	1	1	1	0	0
1	1	1	1	1	1

Figure 6. Truth table displaying output signal for each combination of triggered sensors.

Now that we've established the minimum number of sensors required for a made shot and analyzed the different combinations of sensor responses, we must define the limitations of our ambient light sensors. In a made shot, the basketball may not be exactly perpendicular to the plane of any ambient light sensor. However, according to the datasheet of the ambient light sensors, varying angles between the basketball and the sensor will still yield a nonzero response. Therefore, it is important to determine the maximum viewing angle from the second-closest sensor to the basketball and find the corresponding responsivity at that angle. The sensors are placed around the inner circle of the net in 90 degree increments one inch away from the inner part of the rim. Thus, the maximum viewing angle from the second-closest sensor to the basketball can be calculated as follows in accordance with figure 7.

$$tan(\theta) = \frac{4.25"}{8"}$$

$$\theta = tan^{-1}(\frac{4.25"}{8"})$$

$$\theta = 27.98°$$

In figure 8, we confirm that the responsivity of the ambient light sensor is a strong function of the viewing angle. As expected, the weakest responsivity within the range of the maximum viewing angle occurs precisely at the maximum viewing angle of +/- 27.98°, at which the responsivity is greater than 0.8. Therefore, when testing the ambient light sensor with the basketball perpendicular to the sensor to record the maximum output of the sensor, we know that only values greater than 80% of this maximum value will correspond to triggered sensors [6].

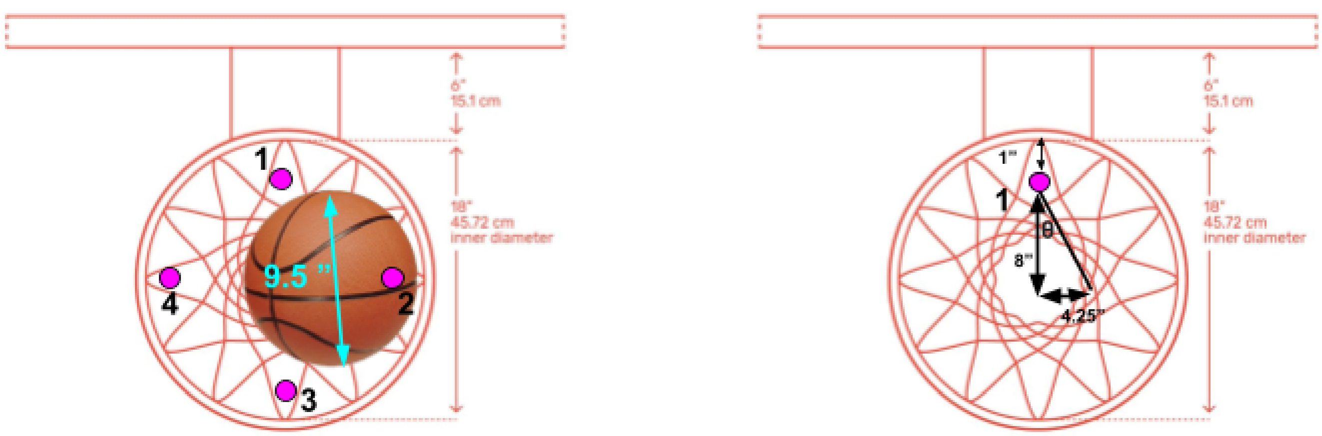

Figure 7. Visual calculation of theta

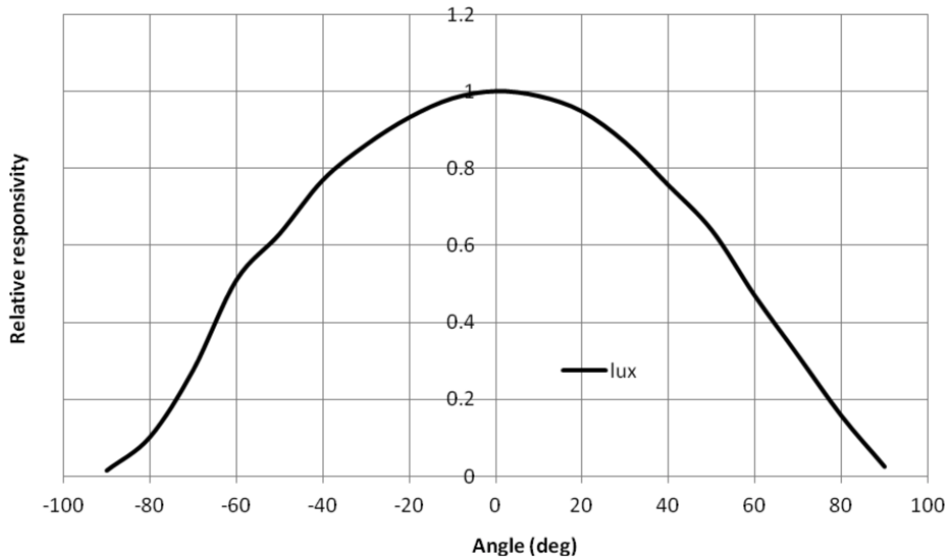

Figure 8. Normalized response of ambient light sensors across viewing angles. [7]

Cost Analysis

- Labor: $39.86/person/hour x 3 people x 10 hours worked/week * 13 weeks worked = $15,545.40 Total [9].
- Parts:

Description	Manufacturer	Part #	Quantity	Cost (per unit)	Machine Shop Labor Hours
DC Power Supply	Gravitech	12V1A-25-POS-WALL	1	$8.69	
Ambient Light Sensor	Lite-On Inc.	LTR-329ALS-01	10	$0.88	
4 digit 7-segment Display	Adafruit	879	1	$9.95	2
Microcontroller	Microchip Technology	ATTINY45V-10XU	3	$1.89	
Mini Hoop [10]	Sklz	088-08-0037	1	$29.99	2
Linear Voltage Regulator	Texas Instrument	LM117H	1	$10.24	0

- Sum of Parts: $83.29, Sum of Costs: $15,628.69

Schedule

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, sensors 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, sensors 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 sensors and complete individual progress report.	Solder connections from game clock display and complete individual progress report.
8 9	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.
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	Bring all hardware to Final Demo.	Bring all hardware to Final Demo.	Bring all hardware to Final Demo.

	Presentation, Continue Working on Final Paper	Make script for final presentation. Start final paper costs and conclusions sections with Rahul and Saud.	Make script for final presentation. Start final paper costs section and conclusions sections with Pranav and Saud.	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 will supervise all of Rahul's responsibilities, Rahul will supervise all of Saud’s responsibilities, and Saud will supervise all of Pranav’s responsibilities.

Ethics and Safety

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 PCB 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. [11]

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.

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