# Strike Zone 2.0

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# Abstract

This project involves creating circuitry and accompanying software to control an automated ball return system, speed measuring array, and display. The goal was to provide a way for baseball players to practice pitching and have thrown balls returned automatically while receiving feedback about pitching speed and the location of the pitch. The finished product can automatically return baseballs thrown into the strike zone, has an LED display for feedback, and has the capability of measuring pitching speed and determining pitch location using an IR array.

# Contents

# 1 Introduction

## 1.1 Objective

Baseball is so popular among the people of the United States that it is affectionately known as Americas pastime. For this reason, it is unsurprising that over one-fifth of adults ages 18- 29 play the sport [1]. This heavy interest in the sport has propped up a large industry in the professional and amature aspects through ticket sales, training, and of course various types of equipment. Engaging in the sport necessitates practicing when possible to improve ones abilities so that the team might have a greater chance of winning. When possible one can practice batting, catching, and pitching with a team or other individuals, but if other people are unavailable one is forced to turn to the use of training equipment. However, training equipment, particularly for pitchers, lacks the type of feedback that training with another individual can provide and is often inconvenient as the baseball once thrown or hit is not returned to the user.

Our goal is to make pitching practice for amateur and hobbyist baseball players as beneficial and convenient as possible. Rather than develop a large expensive system that can evaluate a player at a professional level, we will bring to them a system that provides only the essential feedback on their pitching while making ball retrieval as simple as playing catch with another person. This system will use IR sensors to provide feedback on pitching speed and accuracy and return the ball to the pitcher making solo practice informative and easy.

## 1.2 Background

While there are a lot of tools available to pitchers and baseball players alike, none of these options offer the same level of both convenience and training feedback. The two most common receiving tools for pitchers to use when it comes to training, excluding a catcher and coach, are strike zone nets and ball rebounders. The former is a simple and effective way for the pitcher to practice by pitching into a strike zone where a netting collects the ball. However, this requires a bucket of balls, which are expensive if of quality, and does not give much feedback other than location of pitch which can just be the broad area of the strike zone unless it is split up into zones. The latter, ball rebounders, has been found to be extremely unreliable in terms of getting the ball back to the user for pitching and tend to break due to the strain put on the springs or bands unless you are willing to pay a lot of money. Also, since the ball is returning so quick it is not conducive to pitchers for the sole purpose of pitching and is a better tool for fielding practice.

The Strike Zone 2.0 is offering the same convenience as an actual catcher with even more feedback. For example, the ball will not only be returned, major disadvantage of a normal strike zone net, but will also be able track balls and strikes for the user, as in a baseball situation, and collect and display data such as your speed and zone location, split into nine zones. It is important to note that we are also adding the feedback of speed as well since radar guns are also an important and common tool used for pitchers to train; nevertheless, this also requires an additional person to be able to track speeds unless the system is autonomous. Now, if a pitcher is alone but wants to practice, he would simply need a ball, a mit, and an outlet without the hassle of a bucket of balls and the forever reluctance that all baseball players have of going to fill the bucket back up again. This design combines all important elements and feedback that a pitcher would want for effective and efficient training in one device.

## 2 Design

The training system requires 4 subsystems for successful operation: Power Supply, Control/Interface, Sensors, and Mechanical. The power supply ensures that each of the other subsystems receives the correct power throughout the duration of use. Control/Interface contains several components which discern information from sensor readings and allow the user to see the information they expect displayed in an easy and convenient manner. Sensors handle the measuring of ball pitch location and speed and pass those measurements to the control/interface block. Lastly, the mechanical subsystem handles the returning of the ball to the user.

For speed sensing capability, the original thought was to use to create a doppler radar system. After considering the amount of design required into the radar alone, we concluded that a pair of arrays of IR sensors could be used to calculate the speed which was initially thought to be simple. In terms of the return system, we required a motor that could handle the sudden loading of a baseball. The basis for the design was taken after research in regards to modern pitching machines compared with what was within our budget as well as our power supply. We ended up with a  HP, 2600 RPM 12V DC motor which is consistent with our 12 V supply as well as the power required to launch the baseball back to user and was proven to be able to handle the sudden loading of a baseball. Using these components, we simply modified and improved a typical baseball training net easily found on Amazon.

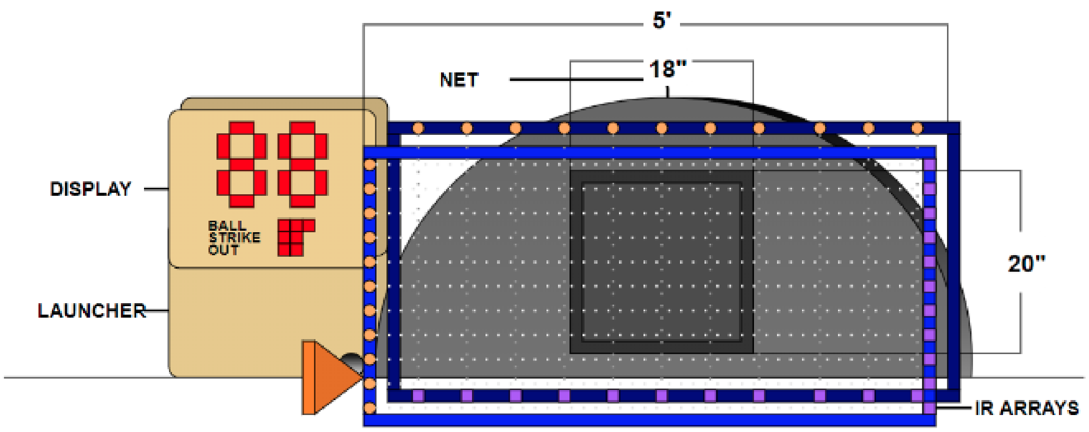


Figure 1: Overview of entire Strike Zone 2.0 project

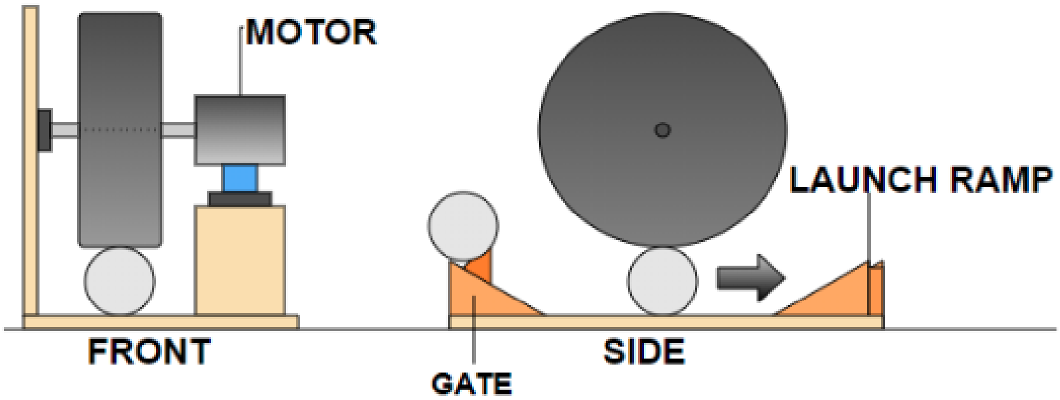


Figure 2: Overview of motor and launcher assembly.

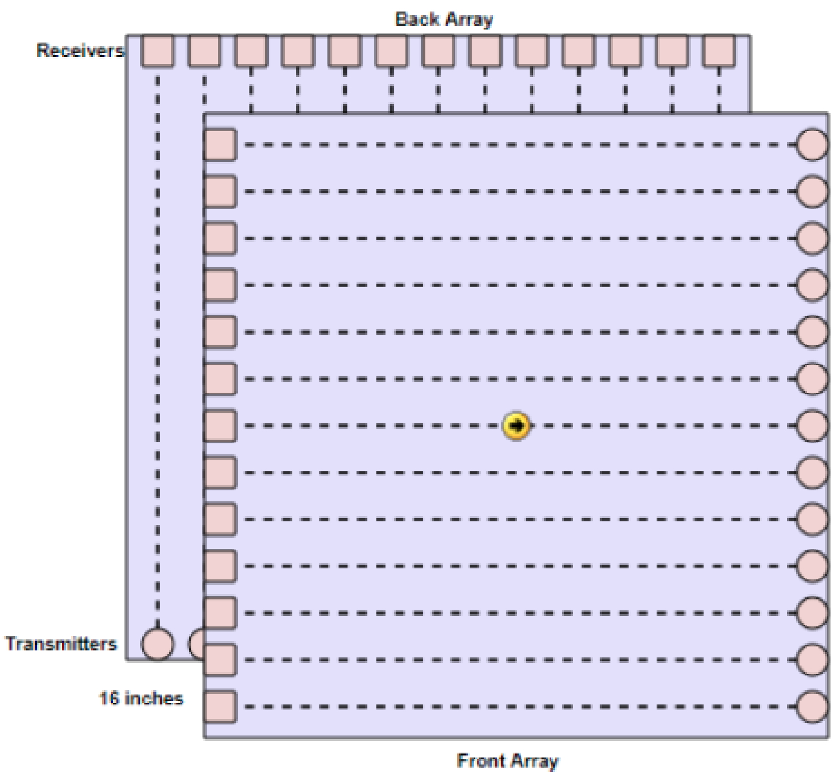


Figure 3: IR Gate sensor array diagram

## 2.1 Block Diagram

Figure 4 shows the various subsystems of our design, including how they interact and integrate with one another. The control/interface components include the microcontroller, LED display, and ball return indicators. The sensors which are distributed on and around the the netting provide the control system with measurements/data. Finally, the mechanical system, with its DC motor, constitute the return mechanism which returns the ball to the user. Together, these various systems form the basis for our design.

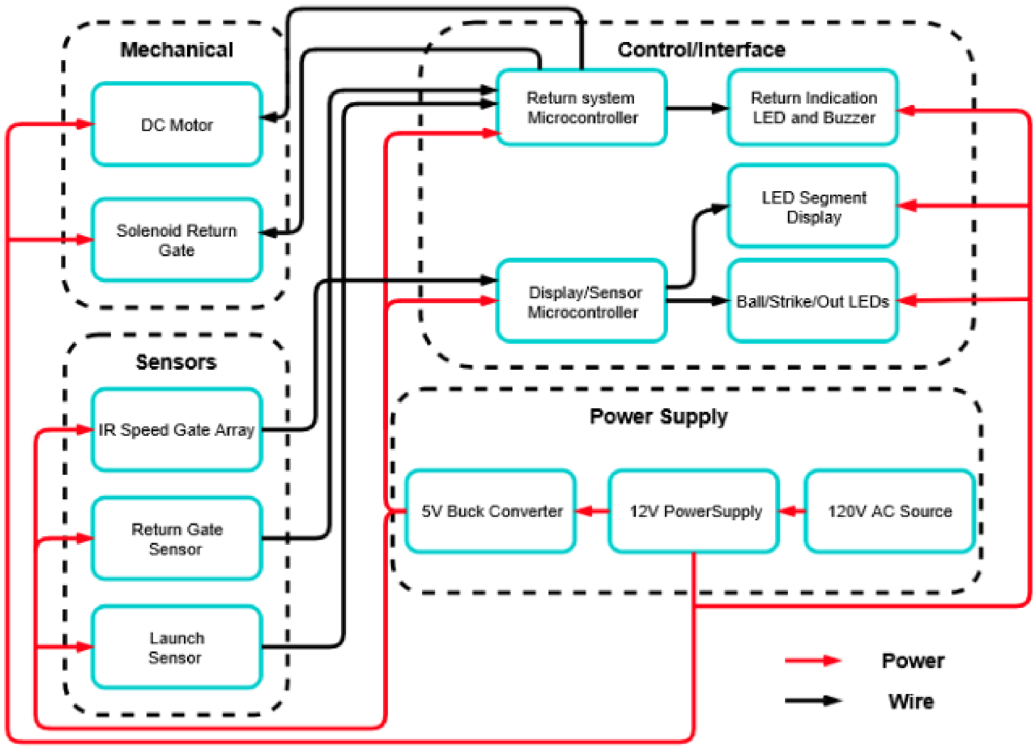


Figure 4: Block Diagram

## 2.2 Power Supply

A power supply is required to power the various sensors and components of the system. To supply the DC motor and various electronics, a 12V power supply will be used in conjunction with a buck (step down) converter. The power supply is intended to imitate the voltage and current of a standard car battery, for future portability.

### 2.2.1 DC/DC Converter

Since the remainder of our components were able to run off of 5 volts, we used a simple buck converter from TI, the LM2596. It was an easily adjustable buck converter that ranges from an input voltage of 3-40V with a max output load of 3A which was more than enough for the components running off of 5V, which came out to be about an amp total. After simply adjusting the potentiometer on the device, it was easily paired with the 12V supply and used as the 5V supply for the components which needed it (IR sensors, microcontroller, etc.). Internal circuit of the buck converter can be seen in figure 5 for reference.

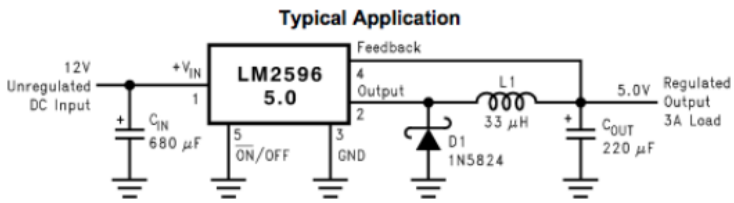


Figure 5: LM2596 Internal Circuit

## 2.3 Control/Interface

### 2.3.1 Display/Sensor Microcontroller

The microcontroller selected was an ATMega328P. The low cost microcontroller was capable of fulfilling the needs of the project. The microcontroller allowed us to communicate with our IR sensors via the analog inputs and to interact with our various LED displays via the digital pins. Combining the functionality of reading from the sensors and outputting to the LED displays streamlined data processing and eliminated the need for serial communication between two microcontrollers that the initial project design required. Inputs into the microcontroller were converted to binary digits after initial processing/calculations was completed and then output to the LED displays using a map between the binary digits and the corresponding segments/light on the display. Processing power was not a concern as the overall code would not need to handle vast amounts of computations and therefore the ATMega328P sufficed. Additionally, the availability of a dev board for programming and testing allowed for easier testing and integration with the connected subsystems before being affixed to its own dedicated PCB (See Appendix C) designed using the circuit in figure 6.

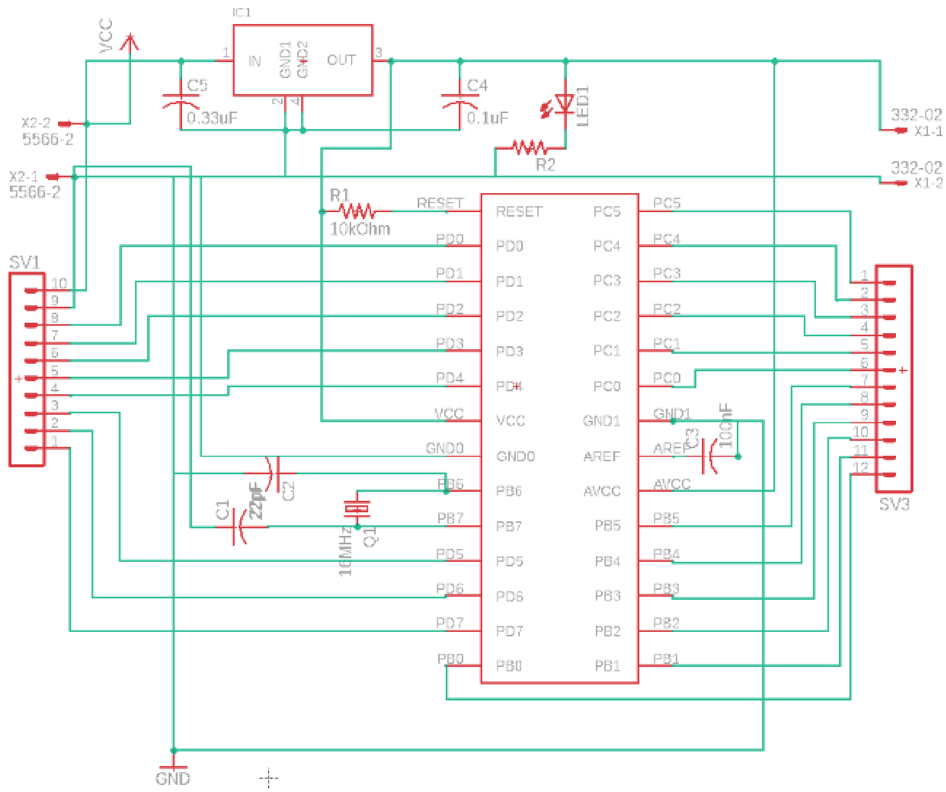


Figure 6: Schematic for microcontroller

### 2.3.2 Motor Microcontroller

A microcontroller, identical to the microcontroller used for the display and IR sensors. This microcontroller is dedicated controlling various parts of the ball return system and the motor. When a ball enters the return system the microcontroller receives a signal from the ball return gate so that the microcontroller can begin generating a 30kHz PWM square wave with an increasing duty cycle to gradually increase the speed of the motor. After a set period the ball stop gate is dropped allowing the ball to roll into the return apparatus. Once the launch gate is triggered, the microcontroller will reset and the motor will be shut off. The circuitry for this microcontroller is identical to that of the display/sensor microcontroller as is the PCB used for mounting it.

### 2.3.3 Segment Display

Primary source of feedback for the user. It consists of 2 7-segment LED displays arranged to display 2-digit numbers. The display is controlled using 8 digital output pins from the display/sensor microcontroller. 4 pins produce a 4 bit binary value for each 7-segment display which represent a digit 0-9 on the the LED driver (74LS47). The LEDs are arranged as shown below in order to produce the desired digits. Two drivers are used per 7-segment display in to drive two sets of 4 LEDs in series per segment in order to improve the visibility of the segments and each display overall.

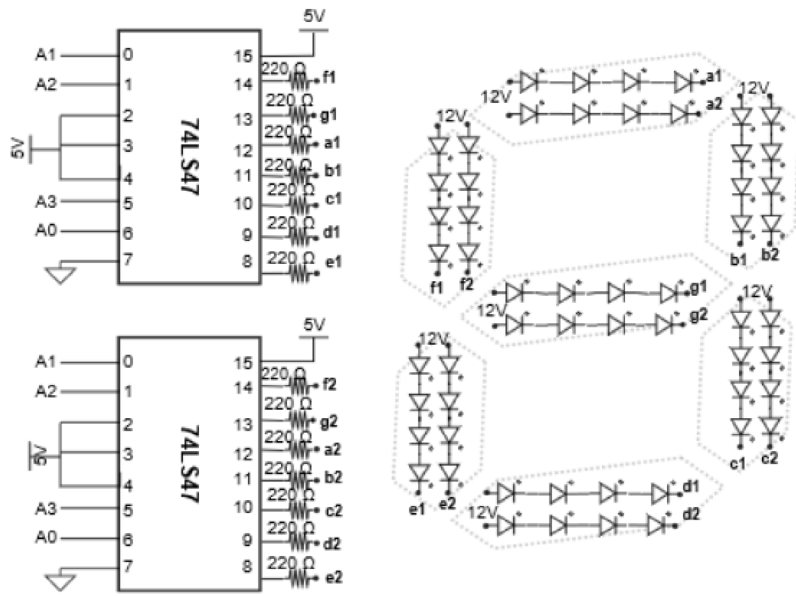


Figure 7: Single 7-segment LED display circuit with 4-bit microcontroller input (A0-A4)

#### 2.3.4 Ball/Strike/Out LEDs

7 groups of 4 red LEDs are used to display various game situations based on whether the ball entered the strike zone or not. The 7 LED groups are controlled using an 8-bit shift register whose outputs are individually connected to 7 separate BJTs. When the output of the shift-register is high, the grouping of LEDs connected to the corresponding BJT will be lit. The data for the shift register is taken from the display/sensor microcontroller. The circuit for the game scenario LEDs can be seen below.

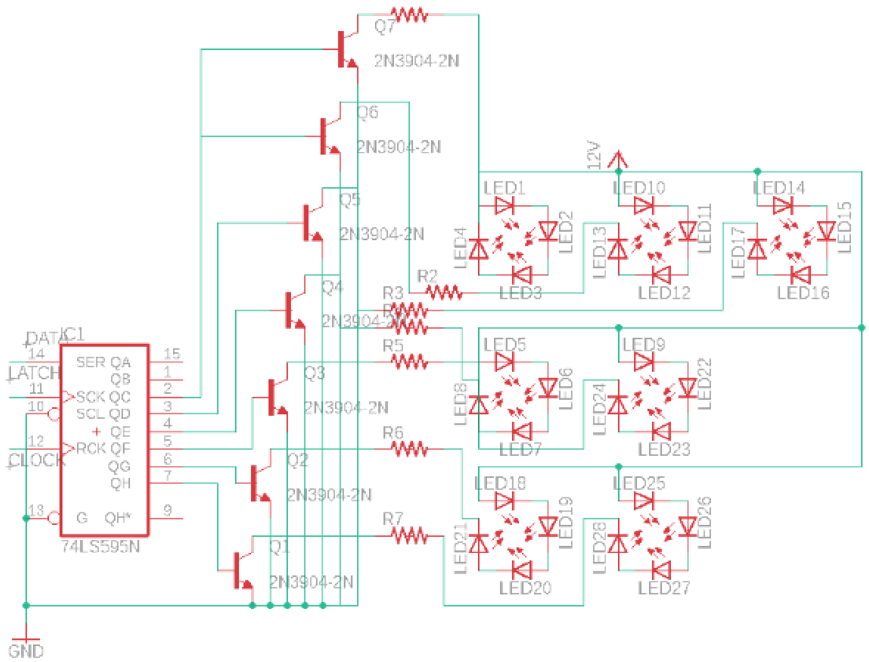


Figure 8: Game Scenario LEDs (from top to bottom: 3 Balls, 2 Strikes, 2 Outs)

#### 2.3.5 Motor Control Circuit

The control for the pitching machine is a simple circuit expressed in figure 9. By using the signals of pressure switches at the beginning of the launch, gate signal, and at the end of the launch, launch signal, the circuit has the ability to tell when the ball is ready to be launched. Once the initial switch is activated, the microcontrollers sends a PWM signal to the gate driver in order to drive the MOSFET to activate the circuit. A PWM signal is used by the microcontrollers to slowly ramp the motor to the desired speed otherwise the spike in current is too much for the supply when directly connected. This MOSFET then drives the motor as well as a warning LED display and 12V buzzer. Once the motor reaches the desired speed, a signal is sent from the microcontroller to activate the solenoid gate and let the baseball into the return system. The ball will then trigger the switch at the end of launch and trigger the microcontroller to stop driving the gate driver and will result in the motor, LED display, and buzzer being turned off.

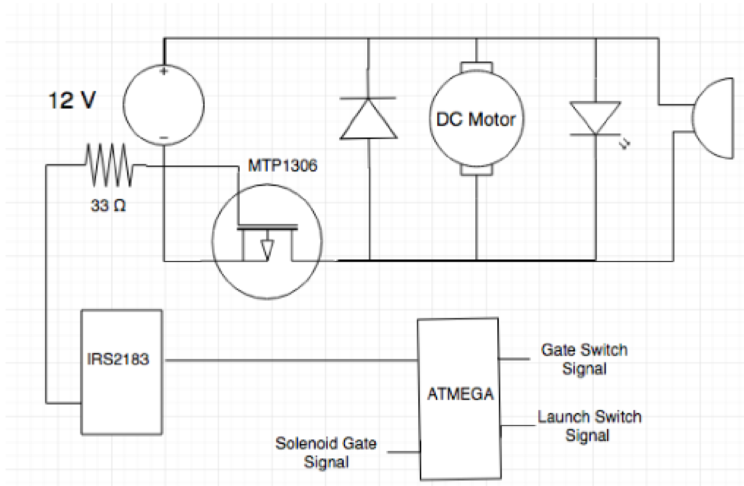


Figure 9: Motor Control circuit

### 2.3.6 Return LED and Buzzer

The purpose of the return LED display and buzzer is to warn the user as well as surrounding people that the ball is about to be launched. The LED display consists of 4 sets of 4 red LEDs in series connected in parallel. Also connected in parallel is a 12V buzzer that increases with the increase of voltage. Both the LED display as well as the buzzer are turned off along with the motor when the ball is successfully launched from the return system.

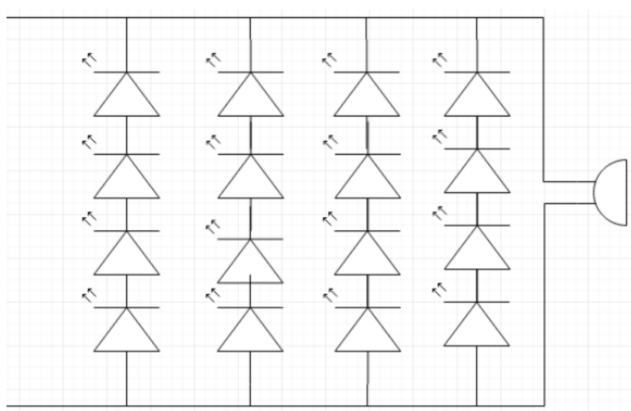

Figure 10: Return LED and Buzzer circuit

## 2.4 Sensors

### 2.4.1 IR Speed Array

IR receiver and emitter pairs used to detect an object passing between them such that the distance between the gates can be divided by the time it took for the object to pass between them, providing a speed.

To determine the necessary time resolution between detection of the arrays, it was decided that a good throw will be around 70mph. In order to have a speed accuracy within  1 mph, it can be shown that the time resolution will need to be about 0.14 msec, which was determined by application of the equations below where $t_1$ is 0.00974 seconds and $t_2$ is 0.00960 based off of equation 1 using 70 mph for velocity 1 and 71 mph for velocity 2.

$$\frac{\Delta X}{V} = t \tag{1}$$

$$t_{error} = t_1 - t_2 = 0.14msec \tag{2}$$

The receiver used is the GP1U52X; a very sensitive IR detector commonly used in remote data transfer applications. The expected signal is a 40kHz, 50% duty cycle which can be overlayed with a higher frequency signal to increase reception sensitivity by a significant amount. The reason that these receivers were chosen over less tuned devices was for the intrinsic filtering which comes with the specialized expected signal shape. The receiver is much less susceptible to outside light sources than its less specialized counterparts. Shown in figure 11 is the required RC filter circuit as well as the attached BJT switch which made the circuit possible.

When the receiver is excited by the expected signal, the output will be low. This creates a bad scenario for connecting multiple outputs together, because any output which goes high will be pulled to ground by the other low signals. To work around this, the outputs of the receivers have been used to drive the base of a BJT which acts as a path to ground for a resistive load. The end result of this setup is that the output is normally high and if any of the receivers is triggered, the whole output node is grounded.

Transmission was accomplished by simple implementation of a timer tuned to the correct frequency (shown in figure 12), and used to drive a BJT which acted as the ground connection for all of the LEDs used (26). By controlling the ground of the LED, the burden of supplying adequate current falls on the 5V source, rather than the timer itself.

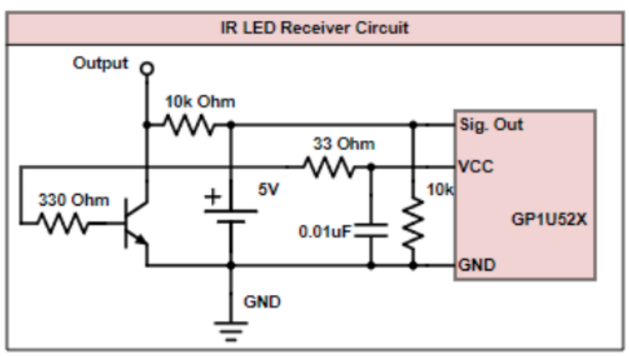


Figure 11: IR receiver module circuit with RC filter and pull-down switch.

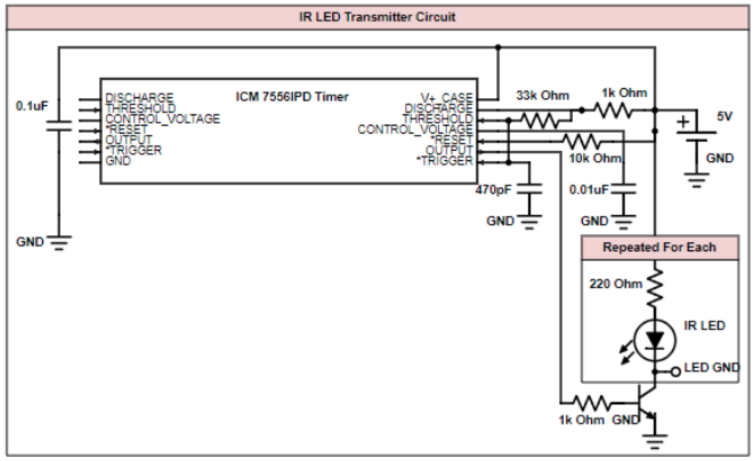


Figure 12: IR LED transmitter circuit.

### 2.4.2 Return/Launch Pressure Switch

Sensors that indicates the ball is positioned at the ball stop gate and is ready to be launched or that indicates the ball has been launched which triggers motor power down process. This is normally high signal which is pulled to ground whenever the switch is activated, as can be seen in figure 13.

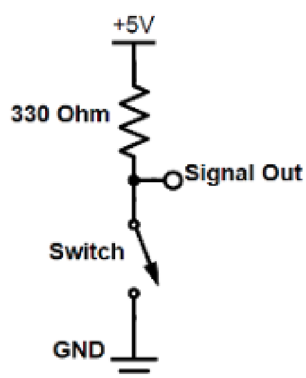


Figure 13: Switch circuit for ball in and ball out switches.

## 2.5 Mechanical

### 2.5.1 Net

This is the physical net that needed to be modified so that the ball would converge to one end of the net and be put in position to enter the return system. This required an addition of a tarp to act as a chute to smoothly roll the ball. The tarp with the addition to a basic ramp at a 6.5° slope made from plywood. This can be seen in the appendix.

### 2.5.2 DC Motor

Primary source of torque and momentum for the ball to be launched back to the user. This motor will need to satisfy certain minimum requirements for being capable of launching the ball the requisite 60 feet from machine to user, as well as consuming minimal power.

Assuming a launch angle of 45 degrees and ignoring wind resistance, the minimum launch speed of the baseball can be found by solving the kinematic equation shown below in terms of the x-direction and y-direction.

$$x_f = x_i + v_i t + 0.5at^2 \tag{3}$$

This system of equations can be solved to show that the required minimum initial velocity is 16.66 m/s (37.27mph). If we model the launch system as the baseball launching from the spinning wheel at the required velocity, then the angular velocity of the wheel can be found as V*r. Where r is the radius of the wheel. The wheel radius will be 0.1 meters, from which we can conclude that the wheel should be turning at 1600 RPM to match the linear velocity desired.

### 2.5.3 Solenoid Gate

A solenoid valve was used as the gate for the baseball to enter the return system. As described earlier in the motor control circuit, the solenoid is triggered by the microcontroller after the baseball has both triggered the initial gate pressure switch and the motor has hit the desired speed. This was triggered in the same fashion as the motor control circuit in the fact that it was driven by a low side gate driver and MOSFET. A circuit is shown below for reference.

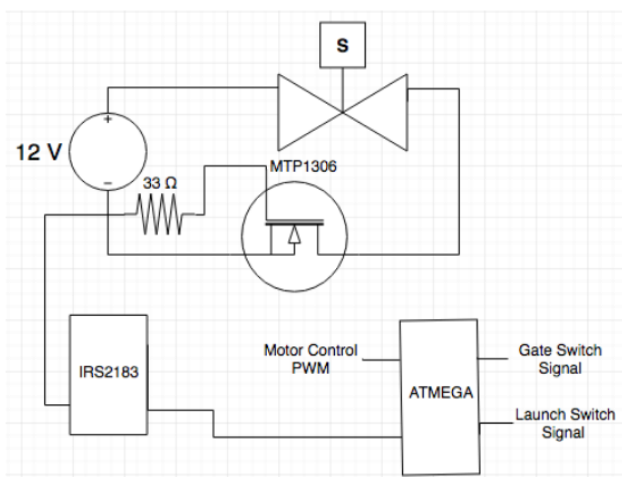


Figure 14: Solenoid circuit

# 3 Design Verification

## 3.1 LED Segment Display

Display integration was fully established, with only the speed output missing. The display system was tested by running a test program which incremented from 00 to 99, and observing this sequence at a distance of 70 feet in direct sunlight. The display was clearly visible at this distance, which surpassed the requirement that the display be visible at 60 feet.

## 3.2 Return System

System integration was successful due to overall operation of the system. The return LED display was visible and buzzer easily heard from the required distance of 60.5 feet. Although the ball did not stay in the air for the duration of the launch, the ball was successfully launched back to the user within a 3 foot radius. The microcontroller properly integrated the system as the solenoid gate did not drop until the motor was up to top speed and the circuit was properly turned on and off by the pressure switches at the beginning and end of the return system.

## 3.3 IR Array

The IR array was tested by observing the output of the receiver at a distance of five feet from the transmitter. The expected output was a strong 5V step immediately following the interruption of the transmitted IR signal. The result of this test can be seen below in figure 15, where the displayed signal is the output of one receiver in a four element array which was constructed for testing purposes. The fast rise time of the signal shows that the receivers are capable of providing the controller with an input which is fast enough to be within the specified range of 0.14msecs.

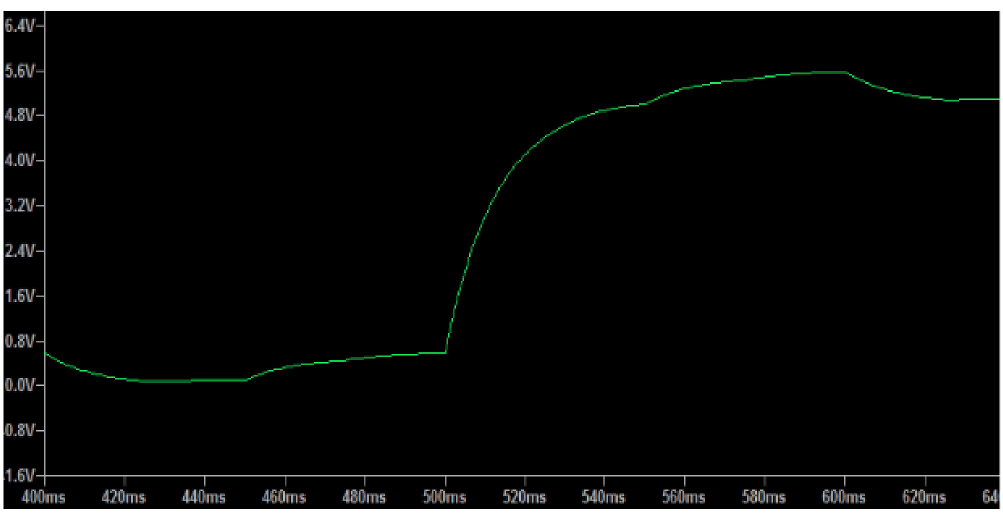


Figure 15: Waveform showing IR receiver output when signal is interrupted.

# 4 Cost

### 4.1 Labor

We estimate 10 hours of work weekly per person at an hourly wage of \$30/hr, with 10 full weeks of work following the projects approval. This results in a labor cost of:

$$3 * \$30/hr * 2.5 * 10hrs/week * 10weeks = \$22,500 \quad (4)$$

### 4.2 Parts

| Part (Serial ) | Manufacturer | Quantity | Base Cost | Total Cost |
|---|---|---|---|---|
| LED Segment decoder/driver | Texas Instruments | 4 | \$1.61 | \$6.44 |
| Red LEDs | Generic | 140 | \$0.10 | \$14.00 |
| IR Emitters and Receivers | Sparkfun | 14 | \$1.95 | \$27.30 |
| DC Motor (Surplus Center) | - | 1 | \$39.95 | \$39.95 |
| Strike zone and netting | - | 1 | \$49.99 | \$49.99 |
| ATMEGA328P Microcontroller | Microchip Technology | 2 | \$2.14 | \$4.28 |
| Prototyping board 4cmx6cm | Generic | 17 | - | \$5.00 |
| 16MHz Crystal Oscillator | CTS Electronics | 2 | \$0.36 | \$0.72 |
| LM2596 Buck Converter | Amazon | 1 | 1.83 | 1.83 |
| 12V 39Amp Power Supply | Mean Well | 1 | \$30 | \$30 |
| Steel Struts | Local 134 | 8 | \$5 | \$40 |
| | | | | |
| Common resistors, capacitors, etc. | - | - | - | \$20.00 |
| Total | | | | \$239.51 |

## 5 Conclusion

### 5.1 Accomplishments

Overall, the project was fun and successful in the fact that the return system did work and was able to launch the ball back to the user. We were able to meet all of the requirements for our individual subsystems; our problems occurred when it came to full integration. While we had issues with the speed sensing, our LED display was visible from our required distance and the integration between LED display and the return system was successful.

### 5.2 Uncertainties

The system with the highest amount of initial uncertainty was by far the IR arrays. No one on the team was familiar with the usage of IR sensors beyond the simplest application, and extensive research was required to fully understand what would be required to implement these sensors. The intention behind using these sensors was to produce the desired speed and position sensing without dealing with seemingly more difficult types of sensors such as doppler. Perhaps the most uncertain aspect of this component was the interaction between nearby receivers and transmitters. In fact, there were many issues involving transmitter signals crossing and triggering neighboring receivers, requiring many impromptu physical filters to be designed, built and implemented.

## 5.3 Ethical considerations

Due to the fact that our device is launching a projectile back at you, there are many safety precautions that must be taken before use. First off, we are designing the return in such a way where the ball is not returned at high speeds, and those using this machine should be prepared and able to catch the ball with a baseball glove. We warn the user that the ball is being loaded and launched through the use of an LED warning light that will switch on when the return mechanism is ready to throw back the ball. The return of the ball also poses the risk or the user or bystanders being struck by the ball so ultrasonic sensors are used to detect whether a person or object is too close to return system and prevent the ball from being loaded until the area is cleared of the obstruction.

Along with the return system, we had to make certain that we do not want to overload the motor or get too close to the rated current and voltage of the specific motor. Since the return system is close to the net, we do not want the motor to overheat such that the netting catches on fire. To avoid this, we stayed well within rated currents and voltages and connect the return system in a way that it is not touching the net. This was more attainable due to the fact that we were not covering a wide range of loads being put on the motor due to only one baseball being launched at a time. Additionally, to assure that the motor did not overheat and cause further damage, the motor was only turned on for the launch and turned off until the next ball was thrown.

Another factor that was taken into account is that this mechanism can be used outdoors. In order to avoid any possible short-circuiting, we advise that the device is not to be used in the rain and must be stored inside. To avoid damage due to rain, the LED display as well the other electrical components such as the sensors and the ball return motor was housed in a water resistant covers that are in line with IP62 regulations to account for rain [3].

In order to adhere by #3 of the IEEE Code of Ethics, we report our expected range of error as well as note that the motor may undergo wear and tear through use over time and will eventually need maintenance [2]. We do not intend on having an individual being hurt by the return system as that is in direct violation of #9 of IEEE Code of Ethics [2]. We are fully aligned our design with the desire to assist colleagues and co-workers in their professional development and to support them in following this code of ethics, #10 of the IEEE Code of Ethics [2]. Even though the device has safety concerns, it is certain to assist in the training and development of amatuer pitchers, and the progress and gain to be made is well worth the safety precautions that must be taken.

## 5.4 Future work

The lessons learned during the process of developing this project have proven to be invaluable. Were we to start this project again from the beginning with the knowledge we possess now, a few things would be changed; the speed/position sensing array, power supply filtering, safety sensors, and overall portability.

In regards to the speed/position sensing array, the original design of an IR receiver/transmitter array proved to be very bulky and difficult to assemble. Each of the receivers required an RC filter and a BJT switch, which resulted in many man-hours being spent simply on assembly. These problems could be overcome with the implementation of a doppler radar system to detect speed and a small array of 8 IR sensors to detect balls outside of the strike zone.

During the integration phase of the project, many microcontrollers were destroyed by a combination of bad USB connections and improper power input filtering. This would be overcome in the future by applying the knowledge gained here to recognize when a controller is being adversely affected by the programming process or power supply, as well as implementing a simple capacitor filter on the power input of all controllers. Obstruction sensing was not fully implemented in our final design, and this is something that would be very important in a commercial product. The reason for the lack of implementation was due to the selected sensor not having a high enough resolution at the requisite distance. Any future attempts at this project would need to implement a more robust proximity sensor for detecting obstructions of the launching system.

Finally, one of the goals of this project was for it to be easy to use and setup. The final implementation was nearly successful in this regard, but the large IR sensor array hampered portability. Improved portability could be obtained in the future through the implementation of a reduced sensor array, and the ability to roll the launching/display platform like a rolling suitcase.

# References

[1] Statista, Share of People Who Play Baseball Regularly in the U.S. 2018, by Age — Statistic., 2018.[Online].Available:
www.statista.com/statistics/227429/number-of-softball-players-and-baseball-players-usa/. [Accessed: 19-Sep-2018]

[2] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available:
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[3] DSMT, IP Rating Chart, 2018. [Online]. Available:
http://www.dsmt.com/resources/ip-rating-chart/. [Accessed: 4-Oct-2018].

# Appendix A Requirement and Verification Table

**Table 1: System Requirements and Verifications**

| Requirement | Verification | Verification status (Y or N) |
|---|---|---|
| 1. Convert 12 VDC voltage from power supply to 5 VDC %1 for all other components | 1. Connect supply to wall outlet<br>2. Read voltage with oscilloscope<br>3. Measure Vpk-pk | Y |
| 2. Output data to LED display within 1 seconds of ball entering strike zone | 1. Provide microcontroller with specific numeric input<br>2. Measure time from input to LED output | Y |
| 3. Handle multiple serial input from the IR gate pairs to determine ball speed within 1 mph | 1. Use radar gun already in possession to verify calculations | N |
| 4. Can turn on ball return system within 1 seconds after detection | 1. Set a threshold reading to the minimum output from IR gate when a ball is present to start return system immediately<br>2. Measure time from detection to return | Y |
| 5. Raise and lower ball gate when signal is received within 1 second | 1. Provide gate lower signal to the microcontroller<br>2. Measure time from signal provided to the time the ball gate lowers | Y |
| 6. Return LED visible within 70 feet in outdoor lighting conditions. | 1. Position LED 70 feet from an observer in moderate lighting conditions, trigger the light and ask the observer to indicate if they see the light. | Y |
| 7. Display data received from microprocessor | 1. Pass arbitrary numeric values from the microprocessor to the LED display and verify that the value displayed is the value being passed in via the code | Y |

Continued on next page

**Table 1 – continued from previous page**

| Requirement | Verification | Verification status (Y or N) |
|---|---|---|
| 8. Display bright enough to be seen from a distance of 70 feet. | 8. Position LED 70 feet from an observer in moderate lighting conditions, trigger the light and ask the observer to indicate if they see the light. | Y |
| 9. Ball/Strike/Out LED display data received from microprocessor | 1. Pass arbitrary ball/strike/out combinations from the microprocessor to the LEDs and verify that the value displayed is the value being passed in via the code. | Y |
| 10. Ball/Strike/Out LED display bright enough to be seen from a distance of 70 feet. | 1. Position LED 70 feet from an observer in moderate lighting conditions, trigger the light and ask the observer to indicate if they see the light. | Y |
| 11. 99% detection rate for speed array | 1. Repeatedly pass a ball between the gates<br>2. Record detect/no detect<br>3. Detection rate is Detected/Total*100% | N |
| 12. Accuracy of detection time within 0.14 msec for speed array | 1. Position array such that a ball may be dropped through it from a predetermined height<br>2. Use kinematic equation of falling object to calculate expected time of detection<br>3. Measure detection time between gates<br>4. Compare calculated versus measured | N |
| 13. Detect when a ball has passed through the launch system 99% of the time. | 1. Repeatedly pass a ball between the gate<br>2. Record detect/no detect<br>3. Detection rate is Detected/Total*100% | Y |

Continued on next page

**Table 1 – continued from previous page**

| Requirement | Verification | Verification status (Y or N) |
|---|---|---|
| 14. Send signal to motor control to power down within 1 second of launch | 1. Simulate shutdown signal by interrupting IR gate<br>2. Check if Motor has begun shutdown procedure | Y |
| 15. Guide the launched ball to a landing area within a 3ft radius of the user | 1. Position launcher requisite distance from pitcher (60.5 feet)<br>2. Launch balls and observe the landing position<br>3. Measure the distance from the user to the ball landing position and determine if it is within the 3ft radius from the user. | Y |
| 16. Max sudden loading must be greater than 0.09 HP | 1. Use electric machinery lab to test and gather torque-speed characteristic | Y |
| 17. Position of strike zone 2.0 stays within 3 inches on any side while motor is in use | 1. Bring motor to operating speed inside the structure<br>2. Measure displacement along the ground | Y |
| 18. Retains ball until motor is up to speed. | 1. Load ball into pre-launch chute<br>2. Set timer in microprocessor to count time when motor is at speed<br>3. Ramp should receive signal from microprocessor to lower<br>4. Check that ramp raises when ball launch IR gate is triggered | Y |

# Appendix B Additional Schematics

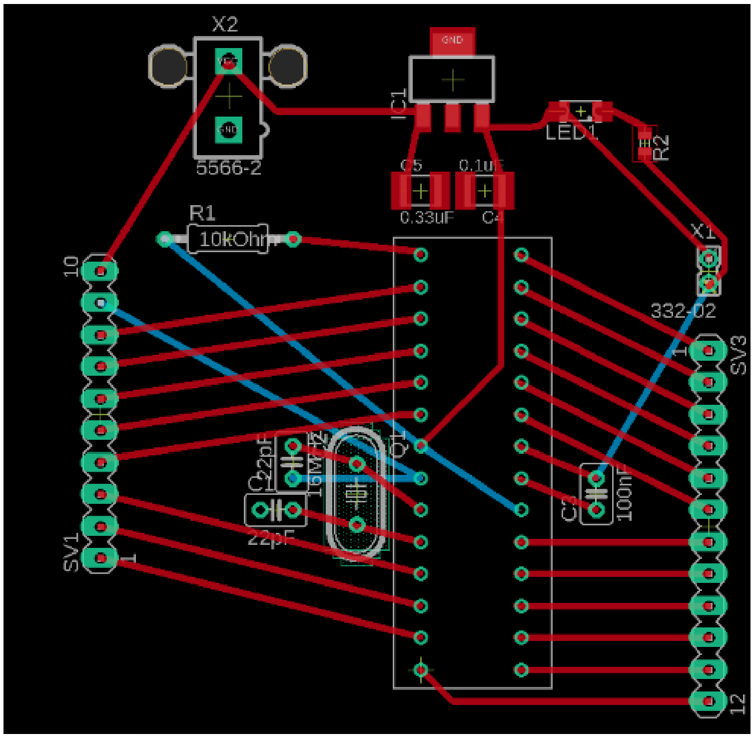


Figure 16: Microcontroller PCB

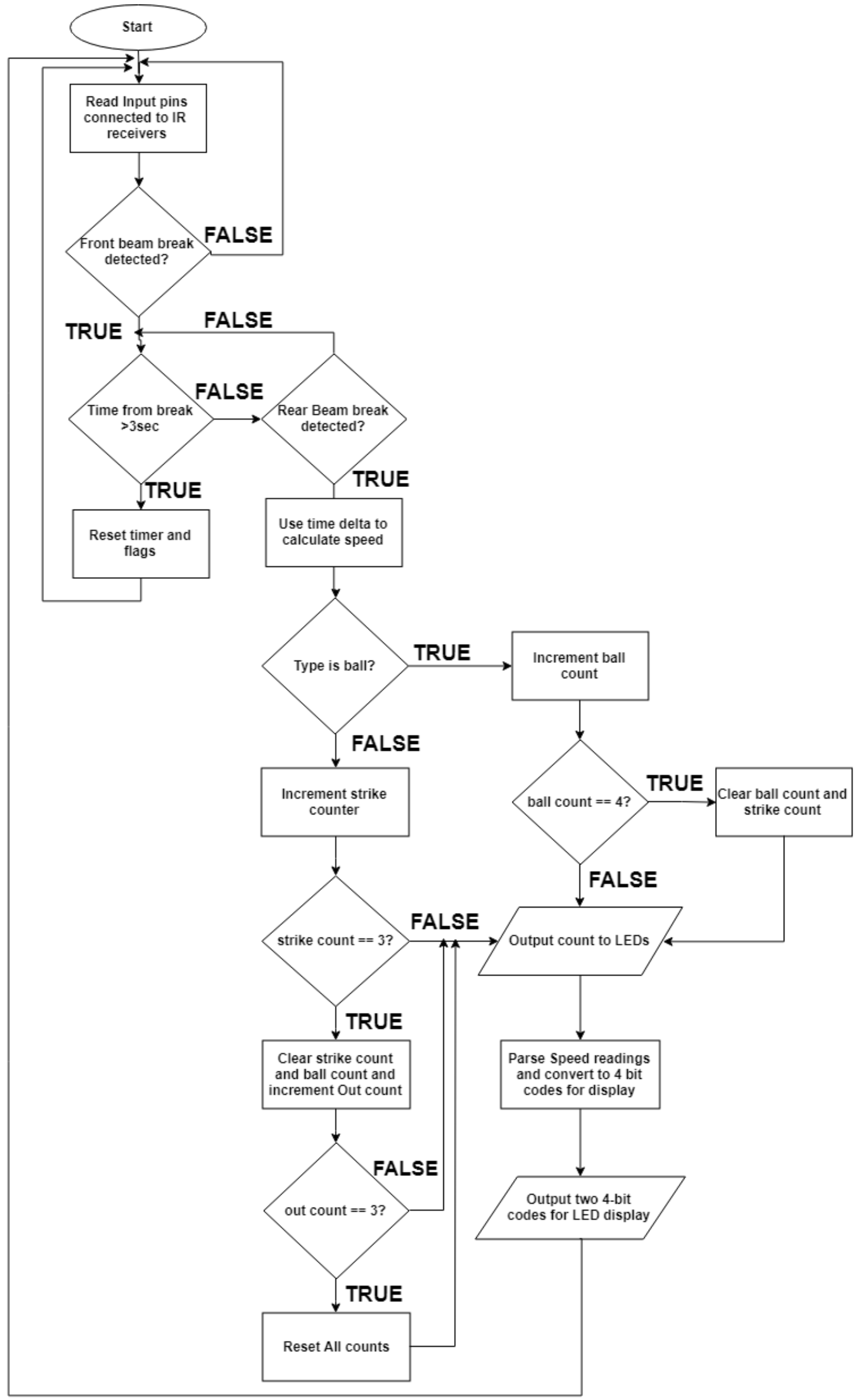


Figure 17: Display/sensor microcontroller Control Flow

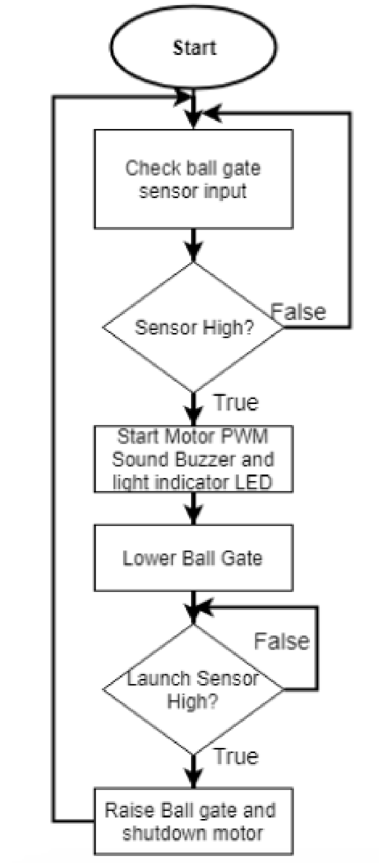


Figure 18: Motor microcontroller control flow