Safe And Sound - Design Document

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1 Introduction

1.1 Objective

Anyone familiar with baseball is aware that all umpires are prone to human error, regardless of experience. One of their key tasks is to correctly call runners as safe or out, which requires a large degree of precision and accuracy. There is no shortage of plays that are merely too close to call for a traditional umpire. Although these close calls may be challenged, the final decision comes from humans and is therefore prone to human error and biases. Our group will solve this problem by designing a base, glove, and shoe system that “knows” with perfect precision whether a runner is safe or out.

1.2 Background

According to USA Today, there were 660 overturned umpire calls in the 2017 MLB season [1]. A subset of these missed calls come from calling runners as safe or out. Currently, the only technology used to challenge these calls are video replays [2]. However, these are still subjective methods prone to human error and biases in addition to not being implemented in every league.

1.3 High Level Requirements

Safe and Sound must satisfy the three following requirements:

1. The base subsystem must set a red LED high if the runner is out. Otherwise, a green LED will be set high.
2. The base subsystem must be able to distinguish between runner foot contact and baseman foot contact with a minimum accuracy of 80 ms.
3. The glove subsystem must be able to correctly recognize that a ball has been caught in it, and transmit this information to the base subsystem.

2 Design

Safe and Sound will be designed using three subsystems: a glove, base, and shoe subsystem. The glove and shoe subsystems will act as edge devices, detecting relevant changes from each player. Meanwhile, the base subsystem will take on the role of a central device by receiving updates from the glove and shoe subsystems as the game state changes.

2.1 Block Diagram

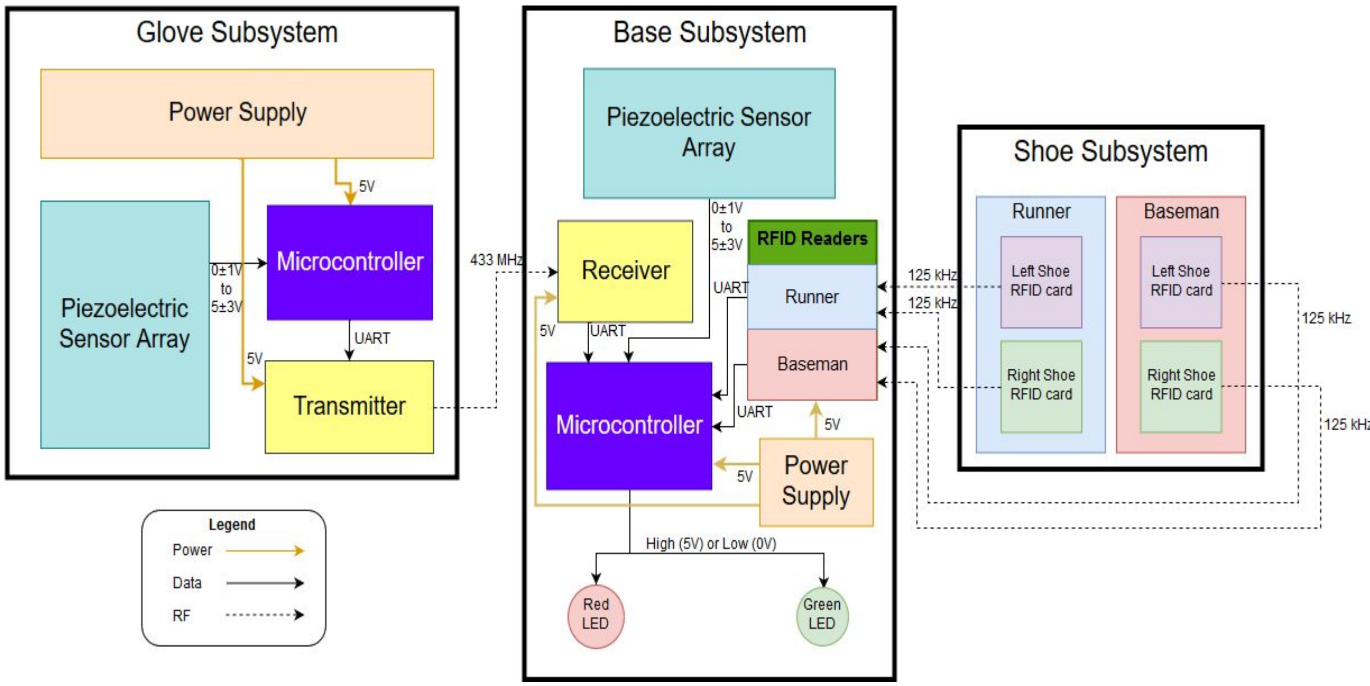

Figure 1: Proposed block diagram for Safe And Sound

2.2 Physical Design

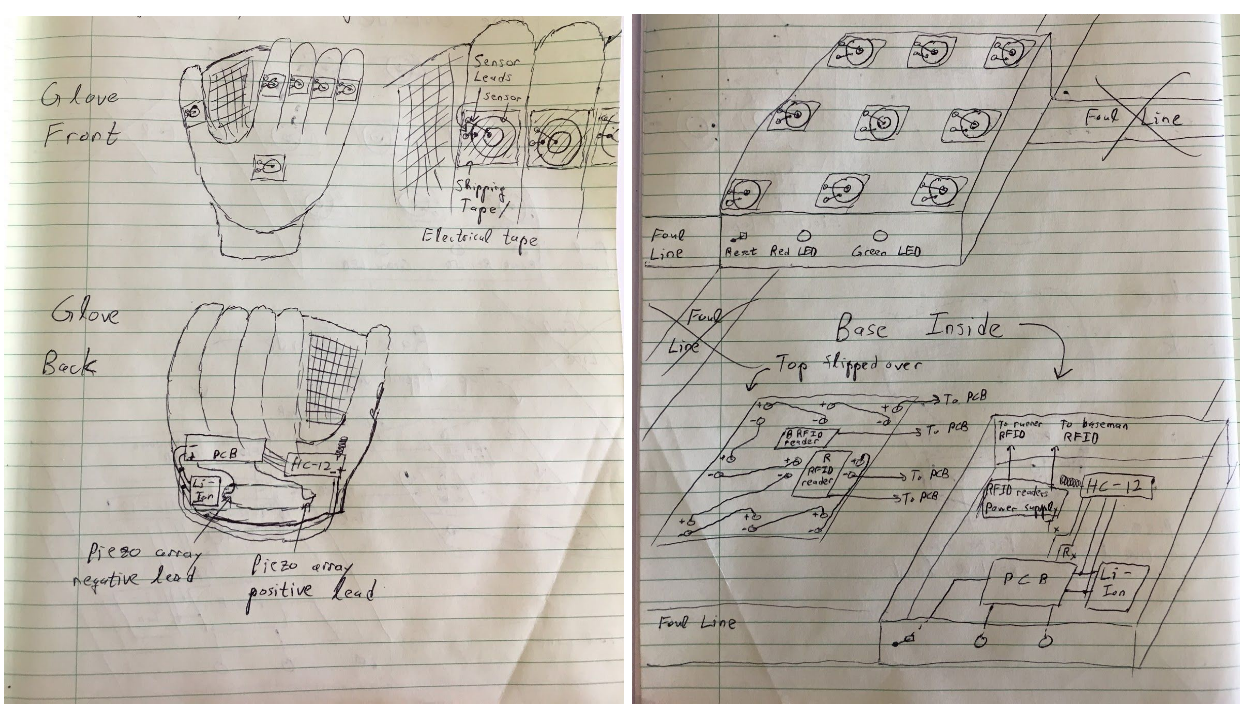

Figure 2: Proposed physical design for Safe And Sound

The glove subsystem will be equipped with six piezo sensors secured to the surface of the glove with electrical or shipping tape. Small holes will be drilled next to each sensor to allow their leads to travel back inside the glove. The negative and positive leads of the piezo array will route through the glove's back opening into the PCB secured on the back. The HC-12 transceiver module and power source for the glove subsystem will also be secured to the back.

The base subsystem will be equipped with nine piezo sensors secured to the top of the base. The positive and negative leads of the piezo array will route into a microcontroller mounted inside the base. Additionally, the power supply, PCB and HC-12 transceiver module will also be mounted inside the base. The RFID readers will be placed beneath the cover of the base near the most common points of foot contact for a runner and baseman.

2.3 Block Design

2.3.1 Glove Subsystem

The glove subsystem's primary responsibility will be to monitor the glove surface for ball impact using several Murata 7BB-35-3L0 piezoelectric sensors and notify the base subsystem of impact events. In addition to piezoelectric sensors, it will utilize an ATMega328 microcontroller and HC-12 transceiver module to process sensor input and communicate wirelessly with the base subsystem. We think piezoelectric sensors are the ideal choice for this task since they don't require external power and are both flat and compact, making it easier to place them on the surface of a baseball glove.

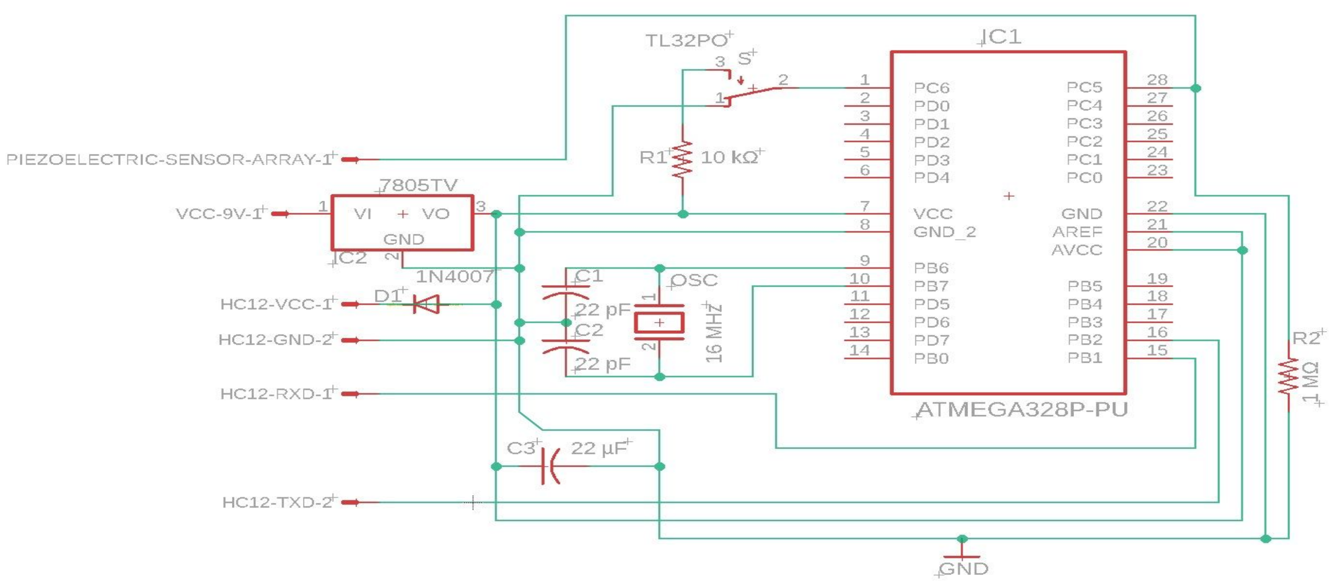

Figure 3: Circuit schematic for glove subsystem

2.3.1.1 Piezoelectric Sensors

A piezoelectric sensor, which utilizes the piezoelectric effect to measure changes in force by generating an electrical charge, will be located on the surface of each finger and the palm of the glove. All six of these sensors will be wired in series and will monitor the glove surface for ball impact. The negative lead of this sensor array will be connected to ground, and the positive lead will be connected to an analog input pin on the microcontroller. While idle, a single piezo sensor will be reading noise that is usually below 5V±0.5V. During direct impact, the instantaneous reading on a piezo sensor will be as high as 20V±5V. Thus, we will define the glove impact voltage threshold as 5V, so any reading that is registered above this threshold will be considered a ball impact event.

Requirements	**Verifications**
Piezo array must produce a voltage reading of 2V±2V when idle	1. Measure idle sensor array reading with prototyping Arduino board
Piezo array must produce a voltage reading above 5V±0.5V when a ball impacts the glove	1. Toss ball into the glove 2. Measure sensor array reading with prototyping Arduino board

2.3.1.2 Microcontroller

The ATMega328 microcontroller in the glove subsystem will be used to process piezo sensor feedback and control the HC-12 transceiver module on the glove. It will receive power from a 9V battery mounted behind the wrist of the glove. Most importantly, it will be programmed to monitor the piezo-array feedback and send the plaintext message “CAUGHT” to the HC-12’s transmitter pin upon detecting ball impact.

Requirements	**Verifications**
Distinguish between piezo readings below and above 5V±0.5V	1. Insert microcontroller into a prototyping Arduino board 2. Program controller to print “above” to serial monitor for reading above 5V±0.5V, and “below” for reading below 5V±0.5V
Be able to send event text to HC-12 transmitter pin	1. Connect an additional HC-12 to a prototyping Arduino board 2. Program glove’s microcontroller to send a test message to the second HC-12

	3. Check the Arduino's serial monitor for receipt of message

2.3.1.3 Power Supply

The power supply will utilize a pair of 9V rechargeable batteries wired in parallel to provide power to the glove's microcontroller and HC-12 transceiver module. The 9V power source will be connected to a LM7805ACT-ND voltage regulator to supply the 5V±0.5V required for the length of an average MLB game (3 hours).

Requirements	**Verifications**
Power source must last for 3 hours to last for an entire game	1. Draw 200mA (HC-12 current draw) + 0.3mA (microcontroller current draw) from the battery 2. Monitor output voltage of battery for 3 hours, ensuring it doesn't deplete below 5V earlier Battery Life = Battery Capacity/Current Draw = (400 mAh / 200.3 mA) x 2 = 4 hours Assumptions: 9V battery contains 400 mAh of capacity

2.3.1.4 Transceiver

The HC-12 is a wireless serial communication module in the 433 MHz range that is capable of transmission up to 1 km away. It will receive glove event information from the microcontroller and wirelessly send event information to the base subsystem. Like the microcontroller, it will also receive power from the 9V battery connected to a voltage regulator to get a 5V input voltage. This module must be able to communicate both wirelessly and reliably with the base subsystem's HC-12 module. It has an over-the-air baud rate of 15,000 bps, so it should be able to send a small string (i.e. "CATCH") to the base subsystem in less than 10ms±2ms.

Requirements	**Verifications**
Reliably send event text (e.g. "CATCH") to the base subsystem's transceiver module in less than 10ms after the piezo array spikes above the glove impact voltage threshold	1. Connect an additional HC-12 to a prototyping Arduino board 2. Program glove's microcontroller to send a test message to the second HC-12

	3. Check second HC-12's serial monitor for receipt of message 4. Ensure time elapsed between beginning of transmission and end of transmission is less than 10ms±2ms.

2.3.2 Base Subsystem

The base subsystem will act as the brain of Safe and Sound. Based on feedback from its RFID readers, the glove's piezoelectric sensors, and its own piezoelectric sensors, it will decide whose foot made first contact with the base and if the baseman was holding the ball. All RFID and sensor feedback will be routed into an ATMega328 microcontroller.

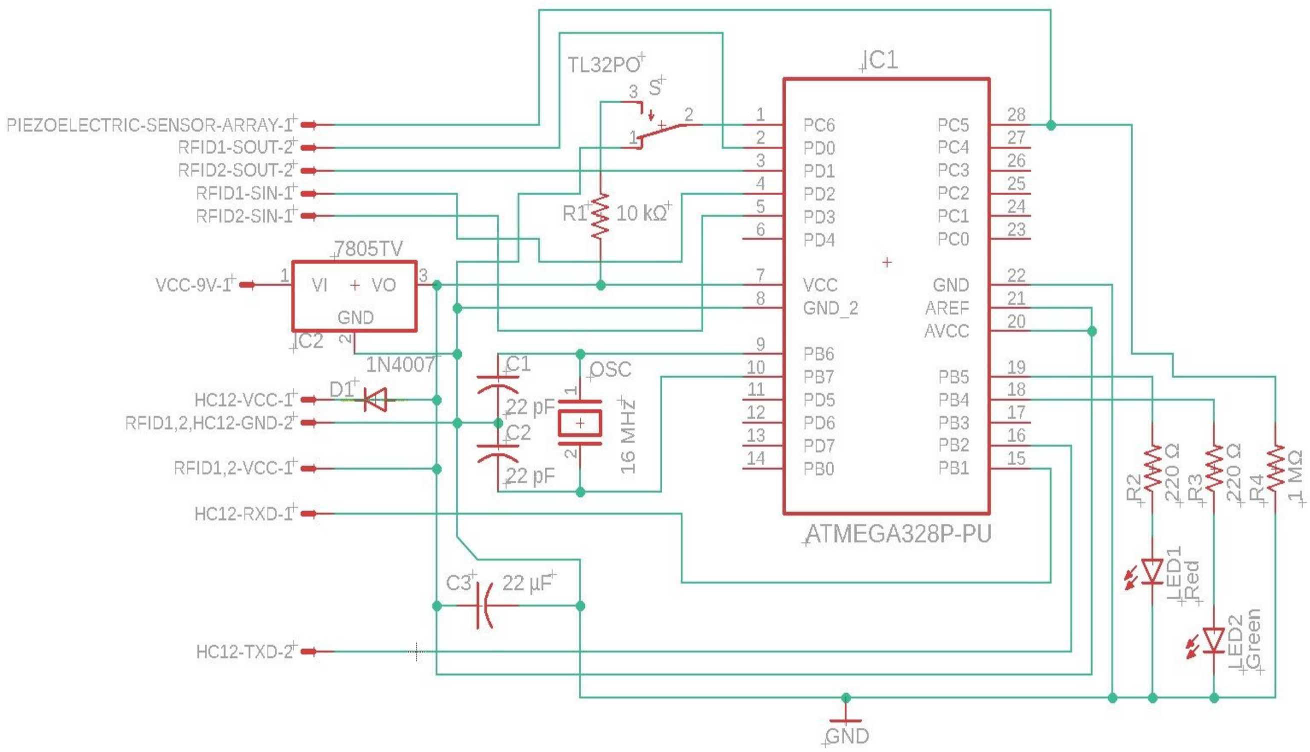

Figure 4: Circuit schematic for base subsystem

2.3.2.1 Piezoelectric Sensors

These will be the same type of piezoelectric sensors used in the glove subsystem. Nine piezo sensors will be secured to the surface of the base and will monitor the surface for physical foot impact.

Requirements	Verifications
Piezo array must produce a voltage reading	1. Measure idle sensor array reading

of 2V±2V when idle	with prototyping Arduino board
Piezo array must produce a voltage reading of 20V±5V when a foot impacts the base	1. Run onto base 2. Measure sensor array reading with prototyping Arduino board

2.3.2.2 Microcontroller

Like the glove subsystem, there will be an ATMega328 microcontroller used to process piezo-array feedback in addition to RFID reader information and event information from the glove's microcontroller.

Requirements	**Verifications**
Distinguish between piezo readings below and above 5V±0.5V	1. Insert microcontroller into a prototyping Arduino board 2. Program controller to print "above" for reading above 5V±0.5V, and "below" for reading below 5V±0.5V
Be able to receive runner's UID from RFID reader when either of the runner's shoes approach the base	1. Insert microcontroller into a prototyping Arduino board 2. Program controller to print runner's UID to the serial monitor 3. Have runner approach the base, and monitor the serial monitor for the UID
Be able to receive baseman's UID from RFID reader when either of the baseman's shoes approach the base	1. Insert microcontroller into a prototyping Arduino board 2. Program controller to print baseman's UID to the serial monitor 3. Have runner approach the base, and monitor the serial monitor for the UID
Receive event text on HC-12 receiver pin	1. Connect HC-12 to microcontroller connected into a prototyping Arduino board 2. Program glove's microcontroller to send a test message from the glove's HC-12 module to the HC-12 module connected to the Arduino board 3. Check the Arduino board's serial monitor for receipt of message

2.3.2.3 Transceiver

The base subsystem will utilize another HC-12 transceiver module to receive incoming event messages from the glove subsystem. The microcontroller will have access to the HC-12's receiver pin on a single digital I/O pin. It has the same over-the-air baud rate of 15,000 bps, so it should be able to receive a small string (i.e. "CATCH") from the glove subsystem in less than 10ms.

Requirements	Verifications
Reliably receive event text (e.g. "CATCH") from the glove subsystem's transceiver module in less than 10 ms.	1. Place base's microcontroller into a prototyping Arduino board 2. Program base's microcontroller to receive a test message from the glove subsystem 3. Program glove's microcontroller to send a test message to the base's HC-12 module 4. Check the Arduino's serial monitor for receipt of message

2.3.2.4 RFID Readers

The two Parallax 28440 RFID readers will have the responsibility of differentiating between runner foot contact and baseman foot contact. We chose to use two readers because the presence of more than 1 RFID tag near the reader at the same time can result in ID collision and corrupt the incoming data. Additionally, each RFID reader should be sufficiently spaced apart from each other physically as an extra precaution to avoid ID collision.

Requirements	Verifications
Runner's RFID reader should correctly send UID information to the microcontroller	1. Connect RFID reader to a prototyping Arduino board 2. Upload code which will read in serial data transmitted by RFID reader 3. Place RFID tag within 3 inches to activate reader to read in serial number 4. Check the Arduino board's serial monitor for serial number
Baseman's RFID reader should correctly	1. Connect RFID reader to a prototyping

send UID information to the microcontroller	Arduino board 2. Upload code which will read in serial data transmitted by RFID reader 3. Place RFID tag within 3 inches to activate 4. Check the Arduino board's serial monitor for serial number reader to read in serial number

2.3.2.5 Power Supply

Like the glove subsystem, the microcontroller, the Parallax 28440 RFID readers, and the HC-12 module will be powered with a pair of 9V rechargeable batteries wired in parallel connected with a voltage regulator to supply the 5V±0.5V required.

Requirements	**Verifications**
The power source must last for at least 3 hours to last for an entire game	1. Draw 200mA (HC-12 current draw) + 0.3mA (microcontroller current) + 9.4mA (28440 idle current draw) from the 9V pair and voltage regulator combination. 2. Monitor output voltage of the 9V batteries for 3 hours, ensuring it doesn't deplete below 4.5 V earlier.

2.3.3 Shoe Subsystem

The shoe subsystem will be the simplest of the three. It's sole responsibility will be informing the base subsystem that the shoes of either the runner or baseman are about to contact the base. Each shoe of the runner and baseman will be equipped with unique RFID tags operating at 125 kHz and will communicate with the base subsystem's RFID readers. Since RFID tags are passive, the shoe subsystem will not require any external power.

Requirements	**Verifications**
Each RFID tag should send its unique 32-bit serial number to its associated RFID reader	1. Connect RFID reader to a prototyping Arduino board 2. Upload code which will read in serial data transmitted by RFID reader 3. Place tag within 3 inches to activate reader to read in serial number 4. Check the Arduino board's serial

	monitor for serial number

2.4 Software

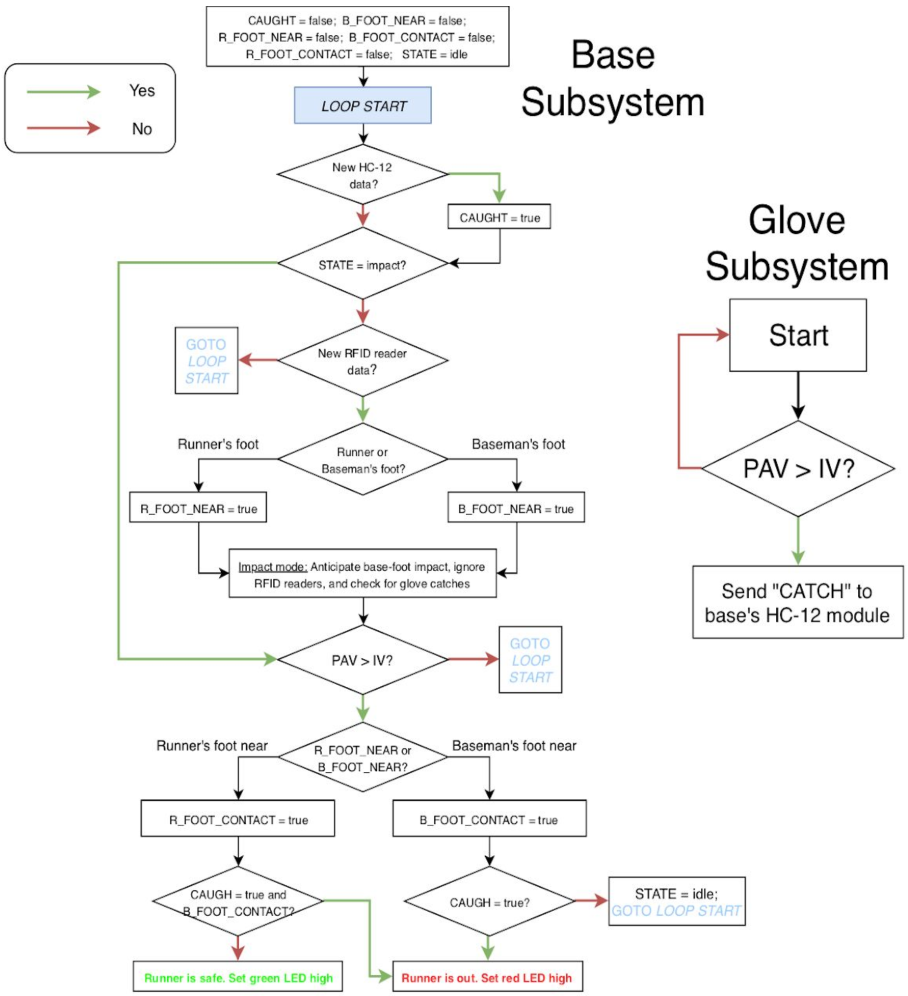

Figure 5: Software flowchart for the base subsystem (left) and glove subsystem (right). Here "PAV" and "IP" are piezo array voltage and impact voltage, respectively.

Both microcontrollers in the base and glove subsystem must be programmed to monitor for ball impact, foot impact, and foot RFID tag proximity. The flow of software in the glove is straightforward. As soon as it detects a piezo array voltage (PAV) larger than the impact voltage (IV), it will send a short message to the base subsystem's HC-12 module to indicate ball impact has occurred in the glove.

The base subsystem's software is more complex. It operates in two different states: an "idle" state where neither players' feet are near the base, and an "impact" state where one of the players' RFID readers has been detected and physical impact should be immediately anticipated. Once physical impact occurs (PAV > IV), the state returns to idle and the final safe or out is made if sufficient information is available. Otherwise, the program returns back to the beginning of the main() loop.

Requirements	**Verifications**
Glove subsystem's software should initiate message transmission if PAV > IV	1. Connect an additional HC-12 to a prototyping Arduino board 2. Program glove's microcontroller to send "CAUGHT" to the second HC-12 if PAV > IV 3. Toss a ball into the glove 4. Check second HC-12's serial monitor for receipt of message
Base subsystem's software should set the green LED high if (1) runner's RFID card has been correctly identified (2) PAV > IV and (3) both these events happen before baseman foot contact and ball-glove contact is confirmed	1. Have runner approach and step over base 2. Verify green LED is set if baseman's foot is on base without ball 3. Repeat, but baseman should have foot off base and catch ball
Base subsystem's software should set the red LED high if (1) it received the "CAUGHT" message from the glove subsystem, (2) the baseman's RFID card has been correctly identified, (3) PAV > IV and (4) all these events happen before runner foot contact is confirmed	1. Have baseman approach base and catch ball before runner approaches 2. Verify the red LED has been set

2.5 Tolerance Analysis

2.5.1 Piezoelectric Sensors

For our project to be successful, there are two key tolerances that need to be addressed, the first being the tensile strength of the piezoelectric sensors. First, we must determine a specific piezoelectric that will be able to stand up to the force of a baseball getting thrown at it. The piezoelectric sensors that we wish to use for this project have a maximum tensile load, P_M , of $250\ MN/m^2$. However, the sensor cannot operate at this pressure. Thus, the type of piezoelectric sensor needed for our design will have to operate between 5-10% of the maximum tensile load [4]. To guarantee that the sensor will work, we can calculate the operational pressure, P_O, by taking 5% of P_M using Equation (1).

$$P_O = C_O * P_M = 0.05 * 250 = 12.5\ MN/m^2 \quad (1)$$

Now that the operational pressure has been calculated, we need to determine how much force, F, a baseball ball will inflict on the sensors in the glove. Using a force equation from basic kinematics, we can determine this force using some assumptions. We can assume that the final velocity, v_f, is zero because we do not want the ball to be moving once it is in the glove. Also, based on some research, we found that the mass of a baseball, m, is 0.145 kg [5]. In order to make sure that the force is maximized, we have to have a maximum value for the initial velocity, v_i, and the average time, Δt. An above-average speed for a throw in the Major Leagues from an infield position to first base is 90 mph, which is 40.23 m/s [6]. An above-average contact time is approximately 0.0007 s [5]. Therefore, using this data, we can calculate for the maximum force made by a baseball on the piezoelectric sensors using Equation (2).

$$F = \frac{(mv_f - mv_i)}{\Delta t} = -\frac{.145 * 40.23}{.0007} = -8333.38\ N \quad (2)$$

In order to make sure that the sensors do not break, we will round up to the maximum force to 9000 N to be safe. Thus, with our F now equal to 9000 N, we can find the area, A, necessary for the piezoelectric sensors to stay intact. By taking our newly estimated F and dividing it's value by our operational pressure from (1), we get the following:

$$F = P_O * A \Rightarrow A = \frac{F}{P_O} = \frac{9000}{12.5 * 10^6} = 7.2 * 10^{-4}\ m^2 \quad (3)$$

Now that we have the area, the radius, r, of the sensor can be calculated using the area of a circle formula.

$$A = \pi * r^2 \Rightarrow r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{7.2 * 10^{-4}}{\pi}} = 15.14\ mm \quad (4)$$

Finally, we can multiply the radius by 2 to find the diameter, D, of the piezoelectric sensor needed for our project.

$$D = 2 * r = 2 * 15.14 = 30.28\ mm \quad (5)$$

After all the calculations, we find that in order for a piezoelectric sensor to withstand the full force of a ball making contact with it, the diameter of the sensor needs to be a minimum of 30.28 mm. Therefore, a piezoelectric sensor with a diameter of at least 30.28 mm and has wire leads attached to it is the 7BB-35-3L0, which has a diameter of 35 mm.

2.5.2 RFID Readers

The response time of the RFID readers will play a critical role in determining the accuracy of this project. Each RFID reader requires 35ms±5ms to read an incoming tag within range, and an additional 35ms±5ms to remain in the idle state before it can read another card. Thus, each reader is estimated to take a total of 70±10ms to read a card. Since the maximum of this time is 80ms, **the base subsystem will have a minimum accuracy resolution of 80ms.** As an example, say the runner arrives at t=0ms, and their RFID card takes 80ms to read. The baseman arrives at t=10ms, and their RFID card takes 50ms to read. The base subsystem would erroneously conclude the baseman arrived first.

Furthermore, after doing some research, we have found that an elite sprinter's contact with the ground is approximately 100 milliseconds [8]. Since even a professional baseball player should not be able to reach the speed necessary to spend less time touching the ground, the base subsystem's minimum accuracy resolution of 80 ms should be accurate enough for the duration of base contact for a base runner. Thus, in order for an umpire to be able to match our system in regards to judging the timing of three quickly occurring events, they would need to also have a perceivability resolution of about a tenth of a second. Therefore, if our system produces accurate results at its minimum resolution for say 95% of the time, it would be very difficult for a umpire to have the same accuracy, so our system would eliminate most of the human error present when deciding first base safe or out rulings.

3 Cost

Our labor cost are estimated using the average annual salary of an electrical engineer from Illinois, $71,166. This annual salary is then calculated to an hourly salary based on a 40 hour work week across all 52 weeks in a year. This presents an hourly wage of $34.21/hour. Additionally, we estimate about that we will work 10 hours for each of the 16 weeks of the semester that we have to complete this project. Calculating the total labor cost for the three of us, we can determine the labor cost as seen below:

$$3 * \frac{\$71,166}{year} * \frac{1\ year}{52\ weeks} * \frac{1\ week}{40\ hours} * \frac{10\ hours}{1\ week} * 16\ weeks * 2.5 = \$41,057.31 \quad (6)$$

Table 1: Labor and Part Costs

Parts	Manufacturer	Product #		Price/part ($)	Quantity
PCB+Shipping	PCBWay			22	1
Microcontroller	Microchip			1.38	2
Piezo sensors	Murata Electronics North	7BB-35-3L0		1.47	15

	America				
4 Rechargeable 9V Batteries + Charger	EBL	FBA_LN-8161*4+ LN-6415		21.99	1
9V Battery Connector	Pacific Science Supply	P56045		3.1	2
5V Voltage Regulator	ECE Supply Shop	LM7805ACT-ND		0.57	2
Crystal Osc	ECE Supply Shop	520-HCA1600-SX		0.57	2
HC-12 Transceiver	Seeed	113990039		12.9	2
Base	Schutt (Jack Corbett MLB Hollywood Base)	12901040		99.99	1
Glove	Rawlings	SL125BF		89.99	1
Cleats	New Balance	L4040		89.99	1
Baseball	Rawlings	ROML		12.99	1
Assorted resistors	ECE Supply Shop	20J10K	10k Ohms	2.03	2
	Yageo	CFR-25JB-52-22 0R	220 Ohms	0.1	2
	Yageo	CFR-25JB-52-1M	1K Ohms	0.1	1
Assorted capacitors	ECE Supply Shop	1C25Z5U223M05 0B	22 pF	0.11	4
	ECE Supply Shop	1C20Z5U103M05 0B	10 pF	0.23	1
LED	ECE Supply Shop	HLMP3507	Green	0.18	1
	ECE Supply Shop	HLMP3301	Red	0.16	1
Reset button	Sparkfun	9276		1.95	2
RFID Reader	Parallax	28140		49.99	2
RFID Tags	Parallax	32399		2.49	2
Testing					
Arduino	Sparkfun	13975		19.95	1
			Total Cost	$ 530.22	
Labor			Annual EE Salary	Hourly EE Salary	
			$ 71,166.00	$ 34.21	
			Total Labor	$ 41,057.31	

			Total Cost+ Labor	$ 41,587.53	

4 Schedule

Table 2: Schedule

Week	Quentin Klingler	Ryan Plyman	Tim Press
2/25	Order parts	Revise design based on Design Review	Revise design based on Design Review
3/4	Prepare glove	Dismantle base	Submit first PCB order
3/11	Start assembling glove subsystem	Start assembling base subsystem	Assist in assembly of both base and glove subsystem and reorder PCB if necessary
3/18	Finish assembling glove subsystem	Finish assembling base subsystem	Complete software
3/25	Test glove prototype	Test base prototype	Test glove and base prototypes
4/1	Refine glove prototype and test integrated system	Refine base prototype and test integrated system	Refine glove and base prototypes and test integrated system
4/8	Begin presentation and prepare for Mock Demo	Begin presentation and prepare for Mock Demo	Begin presentation and prepare for Mock Demo
4/15	Prepare for Group Demo and Final Presentation	Prepare for Group Demo and Final Presentation	Prepare for Group Demo and Final Presentation
4/22	Begin Final Paper	Begin Final Paper	Begin Final Paper
4/29	Complete Final Paper	Complete Final Paper	Complete Final Paper

5 Ethics and Safety

Our design introduces multiple ethical and safety concerns for baseball players and umpires. Player safety is the number one concern for this project, and it is our primary goal that players feel completely safe when using our system. Throughout the development and testing process, any technical decisions regarding specific components or design layouts will include looking to ensure player safety. Thus, in order to best do so, our project will not be implemented in the rain to protect players and the system itself from harm. Furthermore, we will to the best of our ability mitigate risks by following the IEEE Code of Ethics in order “to hold paramount the safety, health, and welfare of the public” [7]. It will be our job to develop a safe product that could be used for baseball leagues of all age levels.

Baseball has been an American tradition for well over 100 years. Umpires have helped keep that tradition alive just as much as players have. Most MLB umpires require years of extensive training and are subject to a very competitive selection process [3]. We all agree it takes a lot of hard work and dedication to become an MLB umpire. With the possibility of complete automation of all umpire-related tasks in future iterations of this technology, it would seem like Safe And Sound is doing a disservice for professional umpires. However, this technology doesn't have to replace umpires entirely. It can be used as an aid for umpires when making very close calls. Plus, there's still many other important tasks that haven't been delegated to automated technology, like calling strikes, foul balls, and ejecting unruly players or managers. Furthermore, as code number five in the IEEE code of ethics suggests, "the understanding by individuals and society" of how the emergence of intelligent systems within sports will affect the game is an important goal to achieve for projects like ours in order to be accepted as tools that can only enhance the accuracy of decision making to allow for fair and unbiased outcomes [7].

6 References

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[5]"The Hit Graphing Calculator Activity",108 Stitches: The Physics in Baseball, 2004. [Online]. Available: https://westernreservepublicmedia.org/baseball/hit4.htm. [Accessed: 19- Feb- 2019].

[6]"Positional Guidelines", Baseball Recruiting 101. [Online]. Available: https://www.gobigrecruiting.com/recruiting101/baseball/positional_guidelines/middle_infielder. [Accessed: 19- Feb- 2019].

[7]Ieee.org, "IEEE Code of Ethics", 2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 21- Feb- 2019].

[8] “Key to speed? Elite sprinters are unlike other athletes--- delivering forceful punch to ground”, SMU Research News, 2014. [Online]. Available: https://blog.smu.edu/research/2014/08/25/key-to-speed-elite-sprinters-are-unlike-other-athletes-deliver-forceful-punch-to-ground/. [Accessed: 7- March- 2019].