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# In and Out Line Monitoring System For Volleyball

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**Report Summary**

The main goal of this project is to create a line monitoring system for volleyball to aid the line judges in their decision making as well as reduce the frequently misjudged calls. Line calling systems have already been implicated into other sports but there is not one yet for volleyball. This is because volleyball must move on to the next point in a matter of seconds or a delay of game is called against a team. Therefore, there needs to be a system that calls a ball without the need of a replay.

The in and out line monitoring system will be able to tell if a ball has contacted the line and is therefore in. To do this, force sensitive resistors will be strategically aligned along the boundary line of the court. If a ball contacts the line, the referee will see an LED light go on on a small device at the head referee stand. If a person contacts the line or there is no contact at all then no light will shine.

The main difficulty in this project is differentiating if a person or volleyball has hit the line. Through many tests, the main difference between the two contacts is the amount of time the impact takes on the line. From testing, a person's duration on the line is 10 times as long as a ball. Therefore, the decision on whether a ball hit the line or a person will be made with time.

Overall, the in and out line monitoring system must be flat so it is negligible to a player, accurate, easy to install, easy to use, affordable and be able to run on battery during a full day tournament. This will ensure a good product to the consumer and also be easily implicated into the game of volleyball.

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## 1. Introduction

Volleyball is a fast paced, competitive game and line calls are an issue that continuously comes up in any level of play. Any line judge trained or not can make an error due to lack of focus, speed of the ball and inaccuracy of the eye. The main goal for this project is to create a line monitoring system to aid the line judges and referees in their decision making and reduce the frequent misjudged line calls. The In and Out Line Monitoring System for Volleyball will benefit both the teams and the referees.

Lack of focus, the speed or the ball, and the inaccuracy of the eye have caused many incorrectly judged calls in the game of volleyball. These calls can be just a minimal point in a game or the deciding factor between the continuation or termination of a season. Judy Katalina, a chair member of the New England Regional Volleyball Association (NERVA) and president of the New England Professional Volleyball League (PVL) says that "at certain levels, the ball is traveling too fast for the line referees to call the lines alone. A bad line call at a critical time can change the momentum or even the outcome of the game" [1]. There needs to be an aid for the line judges to help call the balls that are too close to call.

The In and Out Line Monitoring System for Volleyball will be a line calling aid that is able to tell whether the ball is in by deciding if the ball has landed on the line. This project will be able to relay the information to the head referee whether the ball was in with an LED light indicator. The following report will go over the background, design requirements, design alternatives, preliminary proposed design, final design and implementation, performance estimates and results, production schedule, cost analysis, user's manual and conclusion for the in and out line monitoring system.

## 1.1 Background:

1.1a History of line monitoring systems

Decision making aids in sports have slowly become implemented in the past couple of years. Though no line monitoring system has been applied to volleyball, the history of other sports technologies exposes certain issues regarding such systems effects on society. These accuracy systems contain economic and social issues that make such products difficult to be accepted into society.

The Hawk-Eye line calling system was first seen in cricket in the early 2000's and was used as a broadcasting tool for televised games [2]. After instant replays continuously showed bad calls on live television, hawk eye was then accepted into cricket as an officiating aid. Hawk-Eye provided a system that aided officials as well as ensured fair calls, which lead to the adaption of Hawk-Eye to other sports.

1.1b The effects of Hawk-Eye

Tennis is an old gentleman's game, and therefore unreceptive to modernization. Honor and truthfulness have been at the heart of this game for many years. Whether an amateur player or a professional line judge is calling the shots, the game has always been judged by just the human eye [3]. Therefore the implementation of this modern system, Hawk-Eye, took a while to be accepted into the sport of tennis. It was not until the 2004 U.S Open that clarified the need for the new technology. Serena Williams was playing against Jennifer Capriati and several bad calls were made against Williams. With the help of high definition TV replays, it was clear that the professional judging officials made some unfair calls. As a result, the chair umpire was dismissed from her post and any future dealings

with the U.S Open [3]. In 2007, Hawk-Eye was finally used to settle tough line calls at major tennis tournaments around the world [2].

The Hawk-Eye has been set up to be a system that aids the umpires and line judges with stressful calls. Other than the challenging acceptance into sports, there are other issues with this technology. With Hawk-Eye installed, the judges have become more and more hesitant when making calls. Because players have the ability to challenge the close calls, the officials have stopped making the calls they are supposed to be making [3]. This is an issue the officials need to adjust away from and realize that the technology is there to reduce the stress of calling the lines.

Other than the acceptance of the technology and the hesitation of the officials, Hawk-Eye also has issues with its price. The technology uses 10 high speed cameras to track the movement of the tennis ball to a computer, which is then relayed to another computer to display the trajectory of the ball [3]. Overall, the Hawk-Eye line monitoring system is about $400,000 for one court. Therefore, the richer tournaments and stadiums are the ones that can afford the technology [3].

Hawk-Eye has been and is planning to be introduced into many other sports. Hawk-Eye wants to help soccer officials with off-side calls, assist baseball umpires determine whether a player is safe or out, and possibly tough calls in football [2]. No future plans for Hawk-Eye point towards the game of volleyball.

<u>1.1c Effects of the volleyball line monitoring system</u>

Hawk-Eye gives parallel insight on the possible issues that could come up with the in and out line monitoring system for volleyball. The most important issue that Hawk-Eye faced was the acceptation of the technology into the game. Some may argue that bad line

calls are a part of the game of volleyball. Volleyball has been around for decades and line calls have played only a small factor of the game. Players have had to cope with bad calls through mental toughness and that is a part of being a good player. But, most players and coaches agree that questionable line calls can change the whole outcome of the game. Melissa DeRan, head coach of the Bates women's volleyball team and a previous division one volleyball player at UMASS Lowell comments on line judges, "the line judges are a constant concern for me at the level I work with…It is heart wrenching to have a call be the deciding factor of an important game"[5]. It is clear that a line calling device is needed, but the implementation past the volleyball governing bodies may be difficult to accept considering the history of the game.

Another issue to learn from Hawk-Eye is how the officials will deal with the technology. Today, officials get screamed at by fans, players and coaches if they have misjudged a call. This fear adds a lot of stress to lines judges as well as the head and down referees. If a line monitoring system was installed, the officials may hesitate on calls and slack off on their duties as line judges similar to the officials in tennis. Because lines judges have more duties than just calling the lines, other calls may lack in accuracy as well. Together, this creates an issue not just with line calls but other calls the line judges may make as well.

The line monitoring system has economic issues similar to Hawk-Eye. It is difficult to create a line monitoring system that is cheap. The in and out line monitoring system is budgeted at $5,200 for a whole court prototype. Even if mass produced, the price would still be high and therefore the product would be limited to the gymnasiums, organizations

and schools that can afford it. Like the Hawk-Eye, the line monitoring system for volleyball would be too expensive for use other than professional and high level collegiate.

<u>1.1d Ethics</u>

Overall the line monitoring system for volleyball is involved with economics and social issues, but it also has ethical issues. The social acceptance into the game goes against the status quo for years. Therefore, those in the volleyball world may be against such technology because it is just not what was meant for the game. Volleyball has been played without any form of technology for years and this new system may be rejected by those who do not want change. Accuracy also effects how the system will get implemented. There are always errors in any technology developed, and a line monitoring system built with sensors will definitely have some errors as well. No pressure sensor is 100% accurate 100% of the time, therefore the line monitoring system filled with pressure sensors will also contain some percent error. Volleyball may not accept the system solely based on accuracy. In order to prove its accuracy for it to be implemented into volleyball, a series of tests must be done. The line monitoring system must be put through any type of situation in volleyball. From a hard hit to the back line to a soft tip, the line monitoring system must detect all types of contacts. The system will need to go through many tests in order to prove it is a helpful aid to the game, which could take a very long time. An ethical and economic issue is the price of the in and out line monitoring system. Because the system is so expensive and takes away stress and responsibilities of the line judge, it makes sense to decrease the pay a line judge receives per game. From a line judges point of view this is arguable, a whole game could go by without the use of the monitoring system and the judge

would still get paid less than before the system. This seems unfair to those line judges as they still have numerous responsibilities during a game.

## 2. Design Requirements:

### 2.1 Specifications:

For this project, the design requirements are mostly specific to the game of volleyball and its rules and restrictions but also to the benefit of its users. The in and out line monitoring system needs to be flat so it is negligible to a player, accurate, easy to install, easy to use and be able to run on battery during a full day tournament.

#### 2.1a Flat

On a normal volleyball court, the lines are usually painted down or taped down on the floor as to not interfere with play. In order to have a safe and flat line monitoring system, the schematic should not interfere with the player at all. This is a safety issue as a non-flat line could interfere with the game and cause injury to the players. The maximum estimated value for negligible width is about 1.5 mm, which is the thickness of a penny. This thickness will create a safe environment to play where no player will trip over the line or fall on the line and get hurt.

#### 2.1b Accuracy

The system also needs to be accurate. The project will not be accepted by the sport of volleyball if the system cannot call all types of situations in volleyball. The goal is to create a system that is at least 95% accurate where the line can not only tell when a ball hits the line but can also correctly tell the difference between a ball contact and a person contact. The high accuracy for such a technology will increase the chance that the product will get fully implemented into the sport.

2.1c Installation

The in and out line monitoring system also needs to be easy to install. In order for the system to work in all different types of gyms, the systems will be adaptable in order to be accepted into all venues. With Hawk-Eye, the technology needed to be set up specifically for each venue, for this system an overlaying tape will be easily adaptable to any venue and the installation process will be easy.

2.1d Use

A very important specification for the system is easy use. In the sport of volleyball, a yellow card is given to a team if it takes too long in between points to serve the next ball. Therefore, this line monitoring system needs to give a fast and easy response in order not to further delay the game. Since there are about 10-15 seconds between each serve, the line monitoring system should relay a signal 1-2 seconds after the ball has landed. This time margin will give the referee enough time to realize a close call has been made, look down at the device, see the output, and make the call in a matter of 5 seconds. The output signal, a light, will stay on for about 10 seconds, which will be the time it takes to start the next point. Also, this system will be able to run a full day without charging. A full tournament day of volleyball is a maximum of 10 hours and the system needs to run throughout that time.

2.1e. Cost Effective

The goal of this system is to not be so expensive that some competitive courts cannot afford to buy such a product. As stated earlier, the Hawk-Eye system costs $400,000 to buy and install, which limits the amount of costumers. Only the rich tennis stadiums are the ones that can afford the Hawk-Eye. The goal for this system is that any volleyball gym

will be able to afford this product. From division 1 to division 3 college levels, the In and Out Line Monitoring System for Volleyball will we affordable for all gyms. The goal is that the whole system will cost around $2,000 to $3,000 dollars.

| Goal |
| --- |
| Safety/Flat |
| Accuracy/ Does it work? |
| Easy installation |
| Battery/Use |
| Cost effective |

*Table 1: Goals of the In and Out Line Monitoring System for Volleyball*

## 2.2 Functions

The overall function of the in and out line monitoring system is that it will be able to tell whether a ball has contacted the line. Figure 1 shows the basic inputs and outputs of the system. There would be a contact on the sensing line from either a volleyball or a person. The system would then decide if a ball had contacted the line and output an LED light.

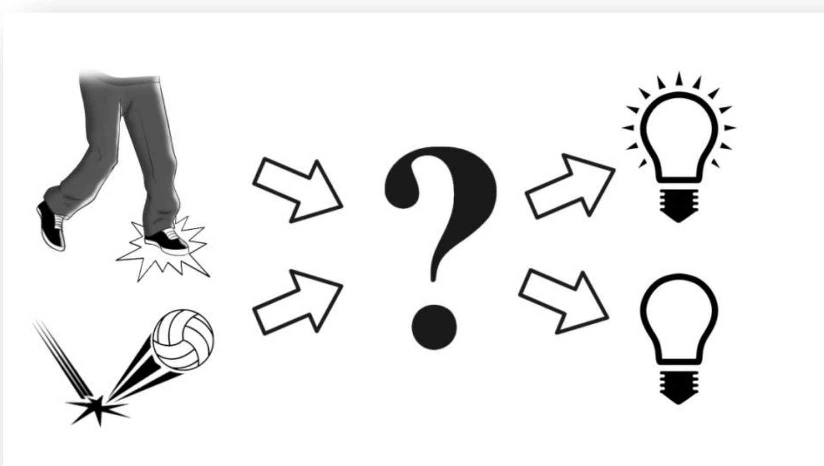

*Figure 1: Basic inputs and outputs of the line monitoring system*

Overall, the main goal of this project is to create a line monitoring system for volleyball. The system will be flat for safety reasons, accurate, easy to install, and easy to use. With these goals in mind, the consumer will be pleased with the performance of the line monitoring system.

## 3. Design Alternatives

### 3.1 Previous Work

There have been many different approaches in solving the issue of line judging. As stated earlier, the Hawk-Eye uses 10 different cameras to follow the path of the ball as well as 2 computers. This system is extremely accurate and easy to use. But, the use of 10 cameras and 2 computers makes the system expensive therefore limiting the number of consumers. Also, the system has to be set up permanently at each venue. With each venue being different, that means a lot of work has to be done to install one Hawk-Eye system. Other than Hawk-Eye, there have been other design approaches that have been patented but not yet executed.

The first patented in and out line sensor is used with light beams [6]. Pedro Carmona describes how light interference detectors can measure the amount of time an interruption has occurred. If an interruption occurs that is less than fifty milliseconds long, then a ball has landed on the line whereas if an interruption is over that time period the interruption is a player. This patent can be used in tennis as well as volleyball. A major downside to this method is the installation. These light beams would need to be permanently installed on a court, similar to Hawk-Eye, which would be extremely costly. Also, a gym is used for volleyball as well as other sports. The installation of these light beams would restrict the use of multiple sports in a gym because they are permanently

installed outside of the volleyball court. Lastly, the biggest issue is that a light beam could pick up an interference by a person the same time a ball is touching the line. Therefore, the system would have a hard time telling that the ball also interfered with the light beam.

Kun-Mu Chen patented a line sensing system using two light beams [7]. The inner beam is placed on the inside of the line and measures the amount of time an interruption has occurred. The outer beam is lined along the outside of the boundary line and detects only interruption. The two beams used can differentiate between a player and a ball. One way is by timing the interruption with the inner beam like the method listed above. The next way is to tell whether both or one beam has been interrupted. If both beams detect interference then the output is that the interruption was a player. If only one beam was interrupted then the interference was a ball. This method also works for both volleyball and tennis courts. This system is an improvement from the above system by Carmona regarding the decision making between a ball and a person. Though, the permanent installation is still a downside to this system.

Wayne Wilson also patented a type of line sensing system using two light beams [8]. Two beams are placed one on top of the other with a distance of 1.5 volleyball diameters apart and .5 volleyball diameters away from the end line or side line. The beams are monitored separately by detectors that sense when a beam is interrupted. If the bottom beam is only interrupted, then the interference is the ball. On the other hand, if both beams are interrupted then it is a player. This system has a great technique of differentiating between a ball and a person. But, similar to previous patents, the permanent installation is limiting as well as costly.

After reviewing these systems, most of the designs require expensive materials as well as permanently installed equipment into a court. To take away from the patented projects is the ideas about differentiating between a ball and a person. Therefore, other options were brainstormed.

3.2 Line Sensing

Because there are significant drawbacks on light beams and other permanently installed sensing systems, sensing will be determined on the line itself. There are multiple ways to sense pressure on the line, one is with capacitive tactile sensors and the other is with force sensitive resistors.

3.2a Capacitive Tactile Sensors

The capacitive tactile sensors capture pressure by measuring the capacitance, which is the ability to store electrical charge. Capacitive sensors are made with a silicone elastic material so when weight is applied the material between the two electrodes can cause the output signal to change slightly with the load staying the same. A drawback to capacitive sensors is that it takes a longer time to detect pressure than other pressure sensors. This is a major drawback in this project since the system needs to put out a signal in a matter of seconds. Though you can speed up the capacitive sensor output with more electronics, it increases the overall coast of the system [9].

3.2b Force Sensitive Resistors

Another alternative to line sensing is use of force sensitive resistors (FSR's). There are many FSR's on the market but this project is limited to those that are flat. The FSR's come in many different shapes: small to big circles, 1.5 inch squares and 2 foot long rectangles. FSR's change their resistance depending on the force and are extremely

accurate; generally they can sense as low as 0.1 Newtons [10]. The FSR's would be easy to install as a piece of tape over an already painted line. The FSR's are also less expensive than other proposed ideas in this section.

The sensor layout is very important. There is a tradeoff between many small sensors throughout the line and fewer longer sensors. Many small sensors would be beneficial because each sensor would be its own input, therefore able to differentiate between a ball and a person more accurately. This is because a ball and a person would not be able to hit the same sensor at the same time because they are too small. Although, assuming there were no dead zones, many small sensors would increase the overall channel count of the system.  If a small 0.5 inch diameter sensor was chosen to cover the whole boundary of the court, 8,640 sensors would be needed. This would mean there would be 17,280 wires coming out of the system. Smaller sensors are also just as expensive as the 2 foot long FSR's. Most of the smaller sensors are only half as expensive. Even though it possible that a ball and a person could hit the same sensor when using long FSR's, using small sensors is not logical due to cost and the amount of inputs the microcontroller would need to read.

## 3.3 Microcontrollers

Choosing a microcontroller is very important to consider in a project. The sampling rate, memory, inputs and easy use are important to consider for this project. Two main microcontrollers used in prototyping are the Raspberry Pi and the Arduino. Even though they come off similar from afar, they are both different from each other in certain ways. The Arduino is a microcontroller that is just a component of a computer. The Arduino is meant to control one basic program task and does not require a full computers processing power or operating system. The Arduino is also generally cheaper than the Raspberry Pi

and easier to program due to most of its consumers implementing basic prototype projects. The Raspberry Pi is a full computer and therefore more powerful and complex. The Raspberry Pi is directed toward software developers and is unsuitable for simple projects [11].From preliminary research the Arduino seems to be the right microcontroller to use for this project.

3.4 Indicator

The indicator will be used to signal if a ball has touched the line. Some indicators to consider are a buzzer or vibration, a light or a sound. The main limitation of the indicator is that it cannot distract the players. Therefore, if a vibration or sound went off then the players may get distracted. A light seems like the more feasible option. This is because it is quiet and also easy to see especially in an indoor gym.

3.5 Battery

Choosing a battery depends on the current draw of the system. The main draw of current is from the microcontroller. Generally, Arduinos run on 6-12V batteries. Another consideration is the power needed for the electronics. A circuit consisting of op amps and resistors will also have a current draw and needed to be powered by a DC voltage. Because the components are small, the voltage cannot exceed the limitations of the electronics used. In conclusion, the battery used needs to be large enough to provide for the microcontroller but not so large that the electronics will burn out.

3.6 Algorithm

The main function for the algorithm is to take a signal and differentiate if the contact was a ball or a person. From the previous patented works and other brainstormed options, duration, magnitude and shape are the options to distinguish between a ball and a person.

The time it takes for a ball to hit the line is shorter than the amount of time a person spends on the line. The issue with this option is that if a ball and person hit the same sensor, the sensor will only read the contact of the person. The next option is the magnitude of the signal. The force of a ball is a lot smaller than the force a person would make on the line. The issue with this option is that most FSR's are limited in the amount of force they can detect, therefore most FSR's will maximize when a person lands on the line. Lastly, shape is an option to consider. The ball impact will have a steeped sloped curve while a person's impact will have a flatter sloped curve. The issue with this option is the same as magnitude; most FSR's will not be able to detect such shapes because the high force will cut off the top of the curve. Also if a ball and a person both hit the same sensor, it would be impossible to differentiate two pressure signals.

## 4. Preliminary Proposed Design

Through continued research, the proposed design for the in and out line monitoring system will be an overlaying tape of the 2 foot long FSR's. The prototype will be 6 feet long (one fifth of an end line) and consist of 9 FSR's with 2 foot sensing sections. The basic block diagram, shown in figure 2, displays the overall process of the in and out light monitoring system. The input is a force from either the ball or a person. That signal is then read by a microcontroller. The algorithm will be able to take the signal and tell whether a ball or a person has touched the line by the difference in duration of the force. The output will then be a green light for a ball touching the line, or no light for a person touching the line.

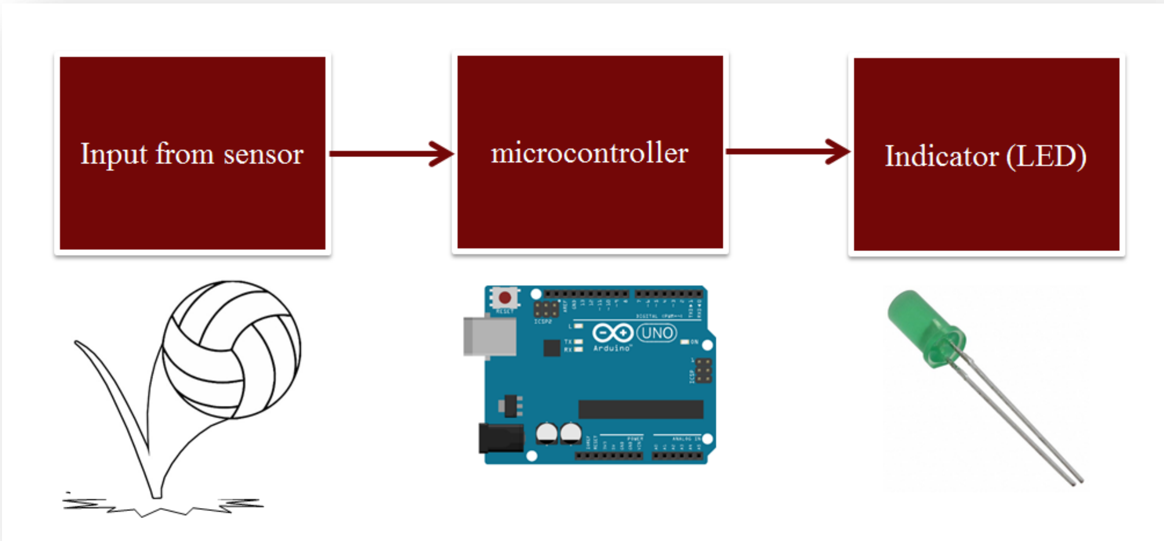


*Figure 2: Block Diagram of the overall line monitoring system*

4.1 Sensors

Figure 3 shows the dimensions of a volleyball court with a highlighted section for the proposed prototype. Based on the first block from our block diagram in figure 2, the FSR's must be placed strategically along the 2 inch wide line so there are no dead zones where a ball could land and not hit a sensor. Each FSR is 2 feet long and has a ¼ inch wide sensing area [10]. From a self-constructed experiment, the minimum diameter a ball will make on the surface is 1 ½ inches. Therefore, three FSR's are needed per two foot section of the prototype in order to avoid a dead zone. The three FSR's over the two foot section will act as its own sensing section of the line and therefore one input to the microcontroller. Figure 4 shows the set up for the sensors on a zoomed in view of the line. The two foot long sensors were chosen over the small sensors due to the cost and number of input wires. A

ball and foot can hit the same sensor at the same time, but that situation is extremely rare. Therefore, that factor did not make a huge impact in deciding what sensor to use.

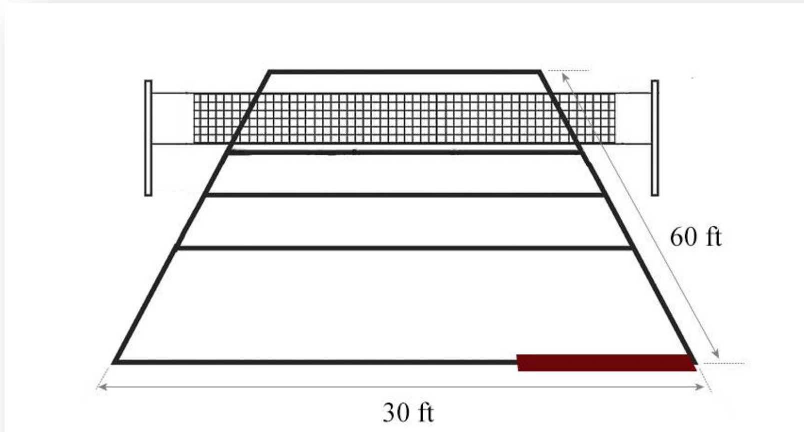


*Figure 3: Volleyball Court dimensions with highlighted 6 foot prototype section.*

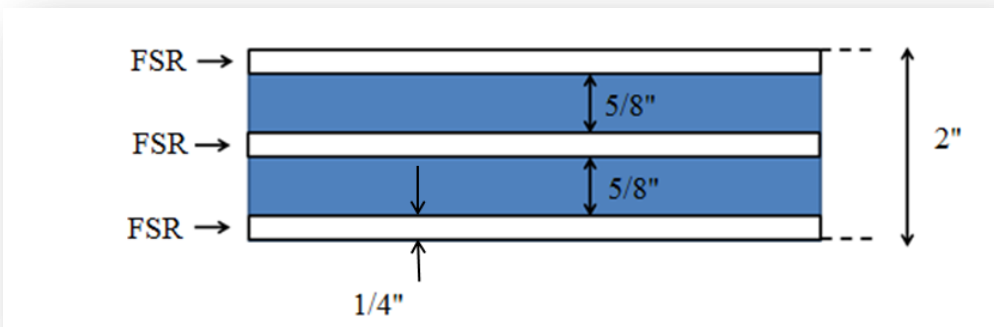


*Figure 4: Expanded section view of chosen sensor layout*

<u>4.1a Width of Overlaying Tape</u>

Another important factor to consider for this system is the width of overlying tape. Figure 5 shows the layers that would be a part of the tape. The first layer is a 2" wide tape. This layer would be only 0.12 mm thick [12]. The next layer consists of the FSR's and wires. The FSR's have a thickness of 0.40 mm [10] and the wires have a thickness of 0.2546 mm

[13]. The wires would go in between the FSR's. The last layer is double sided 2" wide tape with a thickness of 0.23 mm [14]. Therefore the total thickness of the overlaying tape would be 0.75 mm thick. This thickness will definitely be negligible to players during a game because it is much under the designated limit of 1.5 mm.

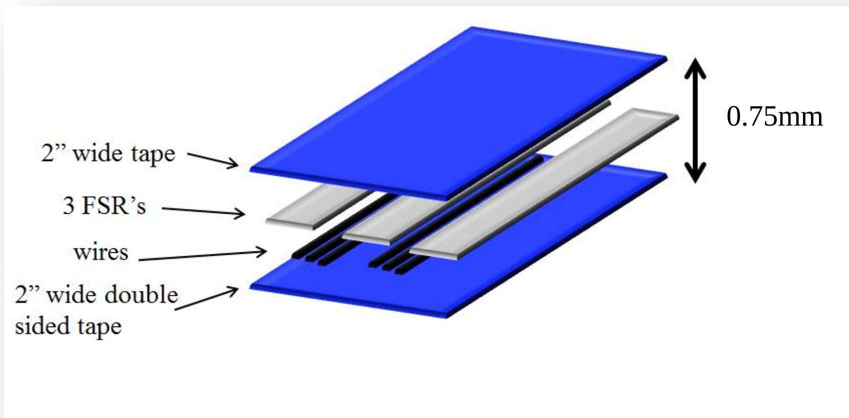


*Figure 5: Layers of the overlaying tape for the line monitoring system*

<u>4.2 Microcontroller</u>

The next factor to consider is the microcontroller that will be used for this specific project. The main specifications to look at in a microcontroller are the number of pins, memory rate, sampling rate and current draw.

The number of pins needed depend on how many sensing areas there are. Because there are three 2 foot sections and an LED indicator, then there needs to be at least 4 input pins for this prototype. The down side to the number of pins in the microcontroller is if the prototype expanded to the whole court. If the product were expanded to the whole court there would be 180 wires coming out of the system. This is because a volleyball court has an 180 foot perimeter and therefore 90 two foot sensing sections. Therefore in the future

there would need to be a MUX to analyze the input pins efficiently and accurately. This is a factor to think about for the future.

The memory rate is not a high priority. The system does not need to store any inputs or outputs. The in and out line monitoring system will be processing real time data instead of recording data in small chunks. This is because for this specific system there will be no replays needed. The microcontroller will read an input signal and output either a light or no light without storing what the output was previously.

The next part of the microcontroller is the sampling rate. The sampling rate is dependent on the input signal. Therefore, some preliminary tests with a force plate were done. The force plate, used in a lab on the first floor of Butterfield, was used for preliminary data. Figure 6 shows a graph of the force of one foot running.

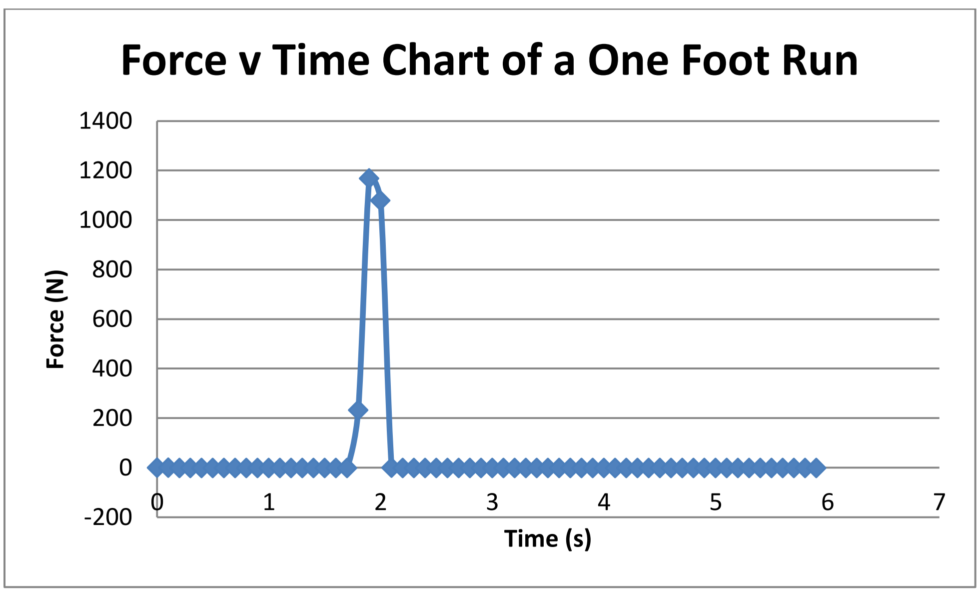


*Figure 6: Graph of Force of One Foot Running*

The sampling rate for the force plate was permanently set at 10 samples a second and could not be changed. The results showed up clear but could be more precise. Therefore it was decided that a minimum of 50 samples a second would be efficient enough for this

particular system because it was 5 times as much as the sampling rate of the force plate. This is a generous minimum given the possible microcontroller sampling rates.

Lastly to think about is the current draw. In order for the system to run a full 10 hour day of a volleyball tournament with no need to recharge, the current draw must be kept as small as possible. It was already previously clear that an Arduino was favorable compared to the Raspberry Pi (see section 3.3), therefore there is only the decision between using the Mega versus the Uno. Based on the specifications above, table one compares between the Arduino Mega and Arduino Uno.

| **Arduino Type** | **Price ($)** | **Number of Digital Pins** | **Memory** | **Sampling Rate** | **Current Draw** |
|---|---|---|---|---|---|
| **Arduino Mega 2560** | 45.95 | 54 | 256KB | 16MHz | 500mA |
| **Arduino Uno R3** | 24.95 | 14 | 32KB | 16MHz | 50mA |

*Table 2: Arduino Mega 2560 versus Arduino Uno R3 [15]*

It is clear from table 2 that the Arduino Uno is the correct choice. Both microcontrollers have enough pins and sampling rate, but the Uno is less expensive and has a much smaller current draw.

## 4.3 Algorithm

### 4.3a Differentiating between a ball and a person

The main function of the microcontroller is to decide if the applied force was a ball or a person. This can be differentiated in the length of time the impact makes, the shape of the signal or the amount of force the impact makes. Using one FSR and a simple voltage divider and buffer circuit, I connected the op amp output to an oscilloscope. The circuit used is shown in figure 12 on page 28. The voltage divider was used with a 100K resistor and paired with a buffer using an LM358N op amp and the circuit was powered by 9V .

After hooking the oscilloscope to the op amp output, multiple volleyball scenarios were tested to see the different output signals. Through testing, it is confirmed that the FSR's are extremely sensitive and high forces ma out the sensor acting as a digital signal. Figure 7 shows the output signal of a foot running across the sensor.

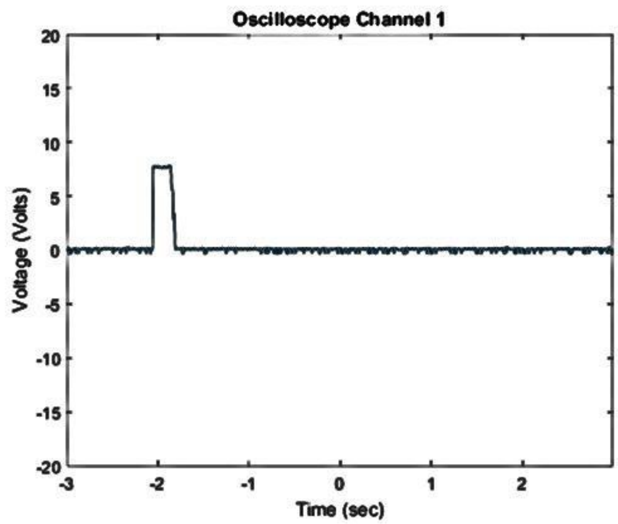


*Figure 7: Graph of Signal of Running Foot Contacting the Line*

As expected, the force of the foot maxed out the sensor around the given input voltage of 9V. Next is to test whether a ball also maxes out the sensor. Figure 8 shows the signal from a hard bounce of a volleyball.

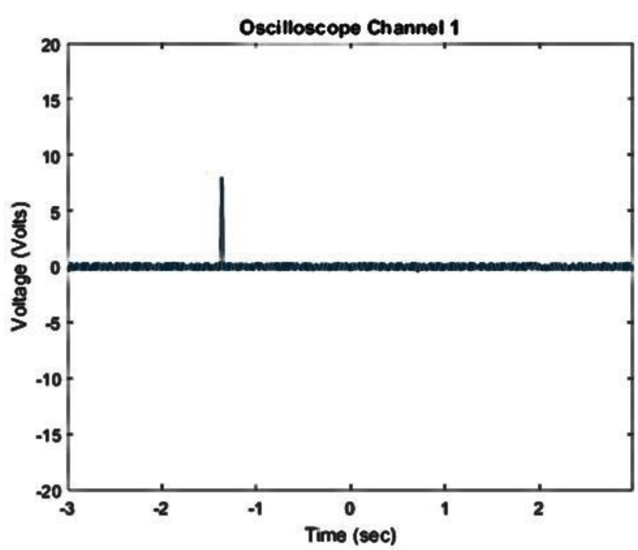

*Figure 8: Graph of Signal of a Hard Bounce Contacting the Line*

The hard bounce also maxes out the FSR. Also, it is clear from comparing figure 7 and figure 8 that the difference between contacts is the length of time the contact makes on the line.

Looking closer at this decision, figure 9 is a higher accuracy signal of a small bounce. A small bounce would contact the line with the longest duration because it is a slow moving ball. Another reason to look at this option is to see if the smallest contact of the ball can also max out the FSR.

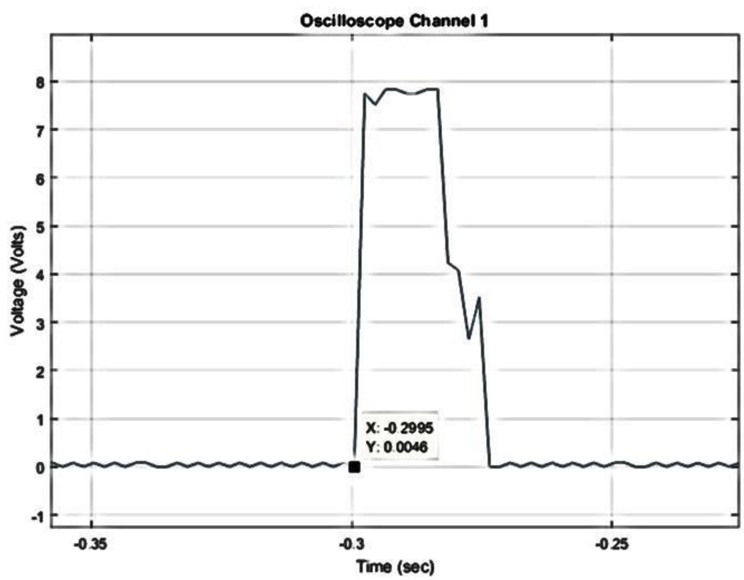


*Figure 9: Graph of Signal of a Small Bounce Contacting the Line*

Using the cursors on MATLAB, the duration of time the ball spends on the line in 26 milliseconds. The small impact of the ball also maxes out the FSR just as a hard hit would. Figure 10 shows a close up signal of a run.

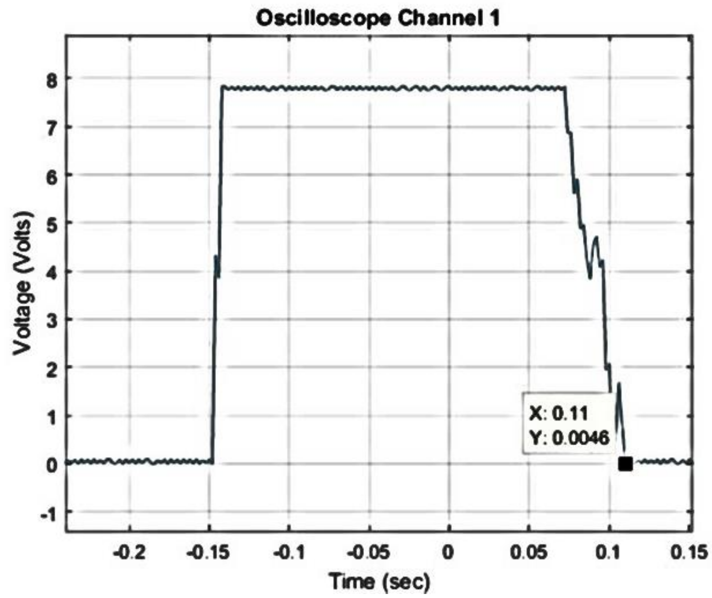


*Figure 10: Graph of Signal of a Run Contacting the Line*

The duration of time the foot spends on the line is 258 milliseconds. This time is about 10 times longer than that of the ball. Both of these scenarios were chosen as extreme cases in order to clarify the decision. A running foot is the fastest contact a person could impact on the line and a soft bounce is the slowest contact a ball could impact on the line. It is clear that the difference in times is the best way to decipher if a ball or person has contacted the line. To further confirm the differentiating, multiple tests were run. Table 3 shows the duration of different impacts on the FSR and also confirms that time can differentiate between a ball and a person. The data cursors on MATLAB were used to calculate the time durations.  The contacts of a person are shaded dark grey.

| Scenario | ΔT (seconds) |
|---|---|
| Bounce | 0.026 |
| Hard Hit | 0.038 |
| Soft bounce | 0.014 |
| Step | 0.516 |
| Run | 0.258 |
| Two Foot Jump | 0.612 |

*Table 3: Time Duration of Impacts of Different Scenarios*

4.3b The Circuit

Relooking at the block diagram in figure 2, the microcontroller receives a signal from the FSR's and either outputs a light for a ball contact or no light for a persons contact. The microcontroller decides the difference based on the time duration of the impact. The best input signal for a microcontroller and this type of scenario is a digital signal.

Looking at the data sheet for the FSR, the most used circuit to convert the signal into a voltage is a voltage divider and buffer. As shown in figure 11, the amount of force applied to the FSR decreases its resistance.

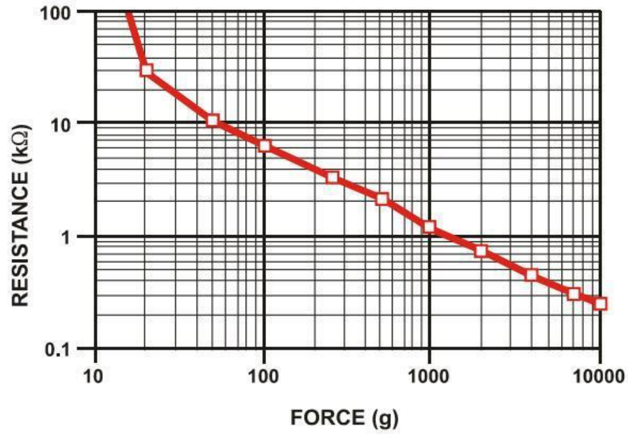


*Figure 11: Force v. Resistance of FSR Graph [10]*

Because the resistance changes with the FSR, the sensitivity of the output depends on the resistor value of RM, as seen in figure 12. Figure 12 is a provided circuit on the FSR data sheet of a voltage divider and buffer. Next to the circuit shows the sensitivity of the output based on the resistor chosen.

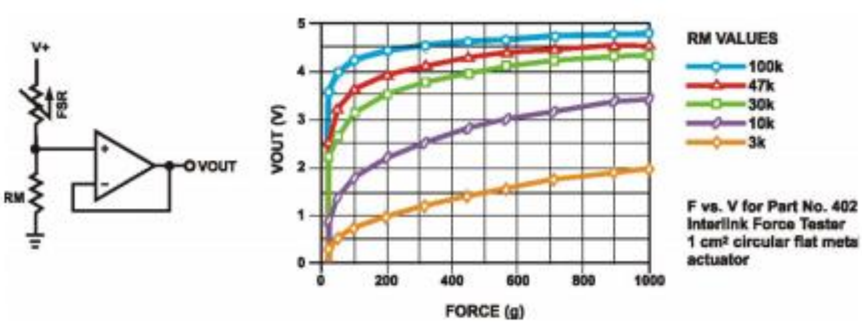


*Figure 12: FSR Voltage Divider and Vout Curve Based on RM Value [10]*

Because the FSR's max out with such little force, the signal to the microcontroller will be a digital signal. Digital signals are the easiest to code for an Arduino. In order to ensure that the signal will always be digital, the chosen RM value of the voltage divider is 100k. That is because a higher RM value creates a more sensitive circuit to force. To confirm the output would become a digital signal, some calculations were made.

<u>Small bounce:</u>

V+=9V

F=600 g → RFSR=1.25k (figure 11)

Vout= $\frac{RmV^{+}}{Rm+RFSR}$

Vout= 8.88V

<u>Person Contact:</u>

V+=9V

F=1200N → RFSR=0.1k (figure 11)

Vout= $\frac{RmV^{+}}{Rm+RFSR}$

Vout= 8.99V

The calculations above confirm that whether an extremely soft bounce occurs or a large force of a person, the output will still be about 9V.

Because each 2 foot section is its own septate sensing area, the three FSR's will be in series. Therefore, the following circuit in figure 13 will be used to achieve a digital signal for the microcontroller. With this circuit, a comparator is unneeded to convert the signal to a digital signal.

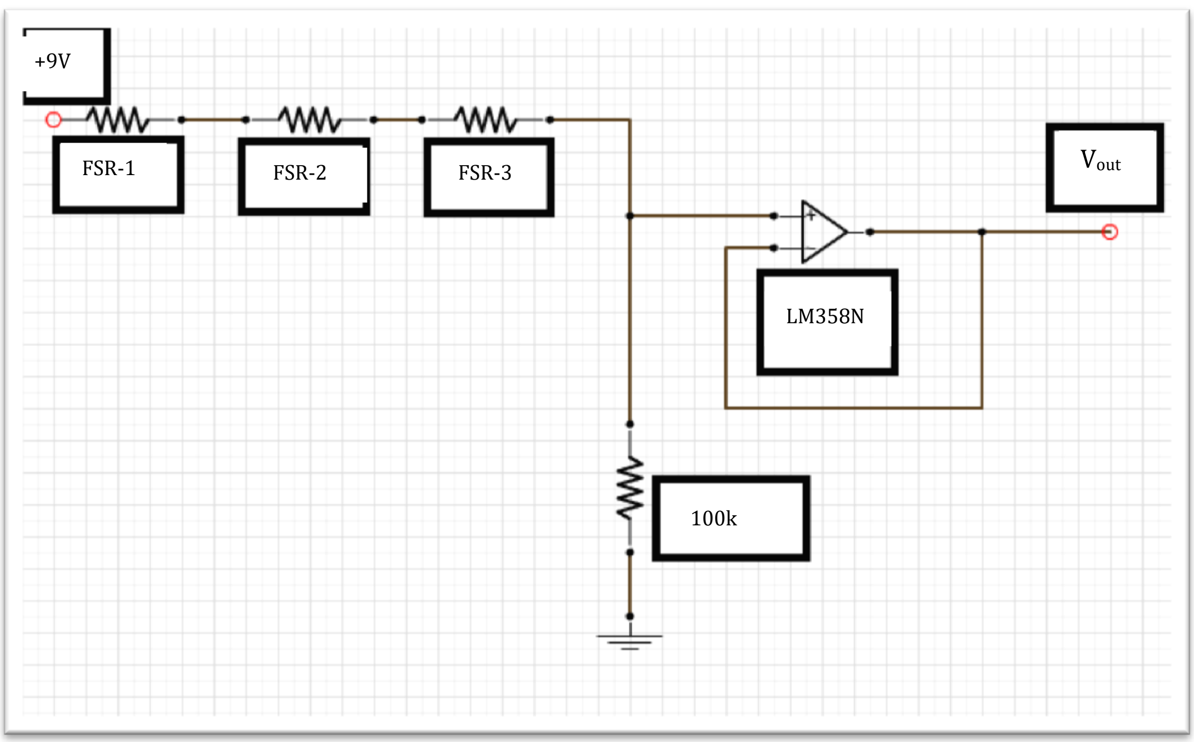


*Figure 13: Circuit Schematic of a Two Foot Sensing Section*

4.3c Coding

The main focus of winter term will be the coding used to support the algorithm. Previously used Arduino codes are available online to modify based on this project. With the help of the online library, coding will be the main focus of winter term.

4.3d Indicator

As previously stated, the options for the output indicator are a noise, buzz and light. The light will be the best option for this scenario. This is because a buzzer or noise may distract a player when on. A light is simple and will be easy to see in an indoor gym.

4.4 Power

The microcontroller is restricted to power between 7-12 volts and the LM358N can handle a maximum voltage of 32V best case [15,16]. Further testing with the prototype is required in order to calculate the current draw used by the line monitoring system. The ideal usage time without charge is 10 hours and an estimated guess is that the system will run on a 9V battery.

4.5 Overall

As described throughout the section, the main parts needed for this system are the FSR's and the microcontroller. These two components are the main purchases for the project, the rest of the budget is found below in table 4.

| Stage: | Part: | Purpose: | Price |
|---|---|---|---|
| **Force Sensitive Resistors** | (9) FSR 408 | Needed to send signal to microcontroller | $161.55 |
| **Microcontroller** | Arduino Mega 2560 | Converts input to output | $39.38 |
| **Op amps** | (3) LM358N | Part of circuit | * |
| **Resistors** | (3) 100K ohm | Part of circuit | * |
| **Battery** | 9V Alkaline, snap | Power for circuit | $3.81 |

| | | | |
|---|---|---|---|
| | terminal | | |
| **Wires** | Soft flex wire | Thin, durable wire to connect components | $11.69 |
| **Output signal** | LED | Provides output information | * |
| **Adhesive** | 3M X Series Double Coated Film Tape, 2" wide | Sticks system to line | $20.15 |
| **Adhesive** | 3M Masking Tape, 2" wide | Top layer of line | $12.50 |
| | | | TOTAL: $249.08 |

*Table 4: Preliminary budget of the in and out line monitoring system. * indicates the component will be covered by the ECE department*

Table 5 shows the timeline for winter term of senior capstone. The main parts of winter term is to code, decide on a battery and test the system.

| **Week Number** | **To do** |
|---|---|
| **1-4** | • Order parts that have not been ordered<br>• Algorithm development<br>• Figure battery usage |
| **4-7** | • Testing on a volleyball court<br>• Rework algorithm if needed |
| **7-10** | • Presentation prep<br>• Final paper<br>• Website |

*Table 5: Timeline for Winter Term*

## 5. Final Design and Implementation

Going into winter term included coming up with a final design, coding and testing the system. Some changes were made to previous design specifications as the process and testing continued. Ultimately, the final design resulted in a working in and out line monitoring system with high accuracy.

## 5.1 Electronics

Each sensing section has three FSR's connected to a voltage divider and buffer. Ideally, the FSR total value should be low when there is a force contact on the line. The combined FSR value should be low in all scenarios, so if only one FSR is hit or all are hit.

First looking at the FSR's in series, if all three FSR's were hit the total resistance would be very low. That is because all three resistors would add up to a low resistance. But, if only one resistor received a force, then the total resistance added up would still be significantly high. This is because there would be two high valued resistors added to a low valued resistor. This would affect the voltage divider and would not have the needed high output voltage.

If the FSR's were in parallel, there would be a better output voltage for all scenarios. Not much of a difference would come if all of the FSR's were hit compared to if the resistors were in series. But, if one FSR were hit, the overall resistance would turn out to be much less than if in series. The output voltage would then be much higher resulting in the desired digital signal. Comparing these two options, it is clear that having the 3 FSR's in the each section be in parallel. This way the output voltage will be high no matter the scenario.

Another factor to relook at is the value of the resistor in the voltage divider. Figure 12 on page 28 gives some suggested values going up to 100K. 100K clearly shows the most sensitive system. A sensitive system is what is desired so the input can replicate a digital signal. Therefore, I tried testing the circuit with 500K and 820K resistors to see if a higher resistance would give a cleaner square wave output. Ultimately, the higher resistance did make the system more sensitive and gave a clean square wave. Therefore an 820K resistor

was chosen for the final circuit. Figure 14 shows the final circuit design of one two foot sensing section.

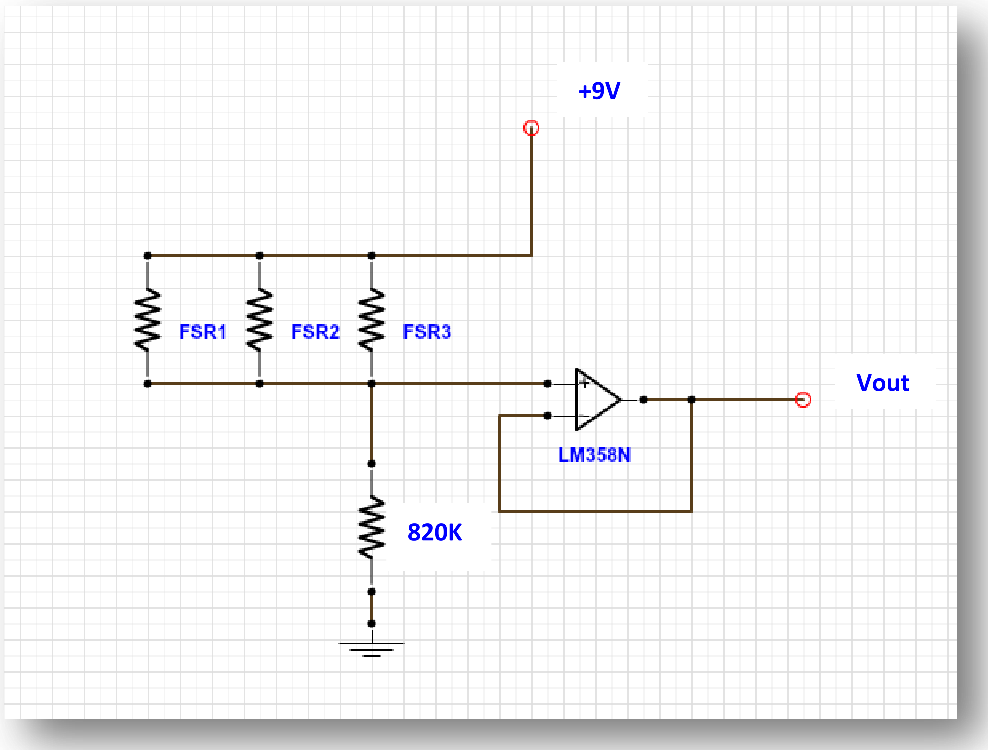


*Figure 14: Final Circuit Design of a 2 foot Sensing Section*

5.2 Algorithm

The main focus of the algorithm is to differentiate between a ball and a person. The algorithm should also output a light for when the contact is a ball. Figure 15 is the flow chart for the algorithm needed to be coded in Arduino language.

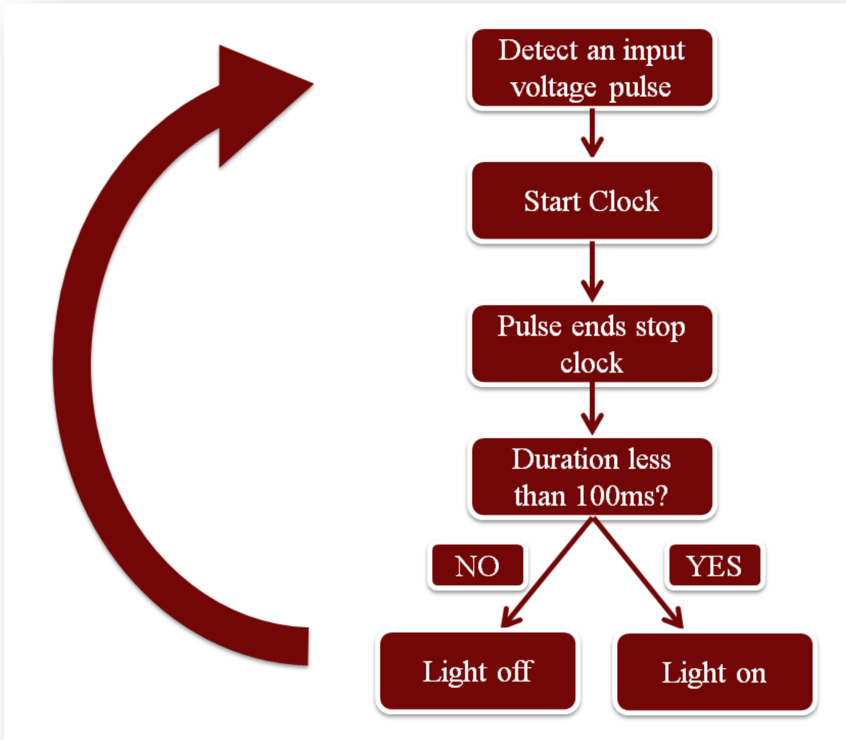


*Figure 15: Flow Chart for Algorithm*

The Arduino will detect an input voltage pulse, a digital signal, from one of the three 2 foot sensing sections. When the pulse is detected, a clock will start and when the pulse ends, the code will calculate the time duration of the pulse. From there the code has an upper limit of 100 milliseconds to tell whether the contact was a ball or a person. Looking back at table 3 on page 27, it is clear that 100 milliseconds would be a generally good cut off point to differentiate the two contacts. The algorithm then would loop through these steps continuously, turning the light on whenever it detects a ball contact. Below is sample code for a 2 foot sensing section.

```
if(digitalRead(PIN_D1) == HIGH) {
  startTime1 = millis();
  while(digitalRead(PIN_D1) == HIGH);
  endTime1 = millis();
}
totalTime1=(endTime1-startTime1);
//Serial.println(endTime1-startTime1);
if((totalTime1)<100 && (totalTime1)>10) {
 digitalWrite(ledPIN,HIGH);
 delay(10000);
 digitalWrite(ledPIN,LOW);
delay (1000);
startTime1=0;
endTime1=0;
```

PIN_D1 is the digital input from one 2 foot sensing section. The function millis() starts a clock , counting up in milliseconds, when a high voltage pulse has been detected. Once the pulse is no longer high, the millis() function takes the difference in the two time durations and that is the total time of the input pulse. The code then tests to see if the total time is in the range of which a ball would contact the line. If it does qualify as a ball, then the LED will turn on for 10 seconds. 10 seconds is enough time for the head referee to realize there was a close call, look at the device, and see if the light is on indicating the ball landed on the line. This code is repeated for all three digital inputs from each 2 foot sensing section. The full Arduino code can be found in Appendix A.

## 5.3 Power

The main specification for power is that the in and out line monitoring system should be able to run during a full day volleyball tournament, which is a maximum of 10

hours long. To calculate what is needed for battery capacity, the current draw was collected for each part of the system. From there the battery capacity was calculated. Below are the calculations that lead to confirm the estimation of a 9V battery.

Number of hours needed: 10 hours
Current draw:
Microprocessor: 50mA
LED: 3mA
Op amp (3): 45nA (each)
FSR's (9): 0.11mA (each)
Total consumption= 54.035mA

Battery Capacity/current draw= number of hours

Battery Capacity=540.35 mAH

**Need lithium ion 9V battery with 620 mAH

From these calculations, the prototype should be able to work for a 10 hour day on a 9V battery.

5.4 Prototype

From the preliminary design the prototype should be 0.75 millimeters thick (see figure 5 on page 21). The actual prototype came out to be thicker than desired. There are multiple reasons why this prototype did turn out thicker than 0.75 millimeters. The preliminary design does not consider that the prototype needs to be portable in order to be brought from a lab to testing in a gym. Therefore, there was an additional layer below the line. It is a 3" wide piece of tape that is doubled up so the bottom is not sticky. This ensures it will not stick to the floor and can be brought to different locations for testing or demonstrating. The thickness of the 3" wide line is 0.06 millimeters thick [17]. Therefore the addition of thickness this adds is 0.12 millimeters because it is doubled up. The total thickness then adds up to be 0.87 millimeters, which is still under the proposed design

requirement of fewer than 1.5 millimeters thick. Another modification from the original proposed design is the location of the wires. It was difficult to lead the wires between the FSR's so the wires ended up going along the outside of the line. Ultimately if this system were mass produced, a machine would easily fit the wires between the FSR's. Since this is a prototype, the wires were placed along the outside due to difficulty. Lastly, a modification had to be made because the pins of the FSR's could not be soldered on directly. Found as a restriction on the data sheet, it is suggested that clips should be used to make the connection. Clips were supplied by the Union College Electrical Engineering Department but were very bulky. There are thinner clips on the market, but due to time constraints of the project the bulky ones were used. This set back was not a huge problem because only the ends of each 2 foot sensing section had a small increase in thickness. The final design layers of the prototype are shown in figure 16.

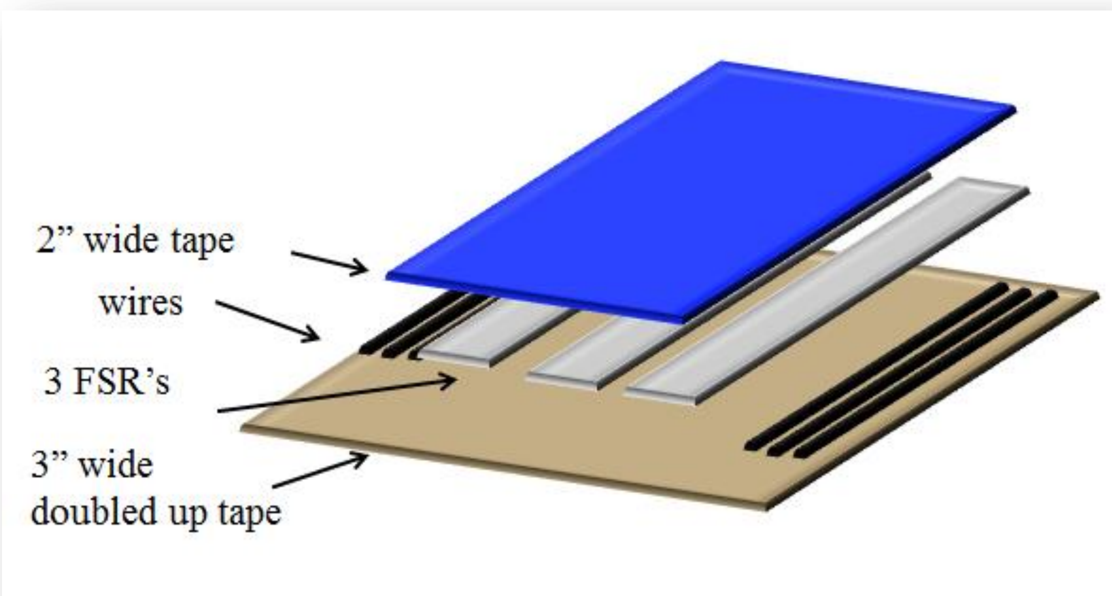


*Figure 16: Final Design Layers of the Overlaying Tape*

5.5 Overall

All in all, the final design did not change much from the preliminary design. The major changes came from the circuit and prototype setup. The final design also improved the detail of power and especially the detail of the algorithm.

## 6. Performance Estimates and Results

From the proposed specifications, the ideal accuracy of this system is 95%. Because this is a prototype, the expected accuracy can be given a leeway of about 5-10% less than the ideal accuracy of the system. The variance in accuracy comes from how the final design differed from the proposed design. With wires on the outside of the line and the line not permanently stuck to the floor, there is room for error in the prototype itself. There are two steps of testing needed for this system. The first is testing how well the Arduino works with the FSR's in measuring the duration of the impact. The second tests is how well the prototype works at the volleyball gym with volleyball players.

6.1 Testing the Arduino's Accuracy for Measuring Impact Duration.

To test the accuracy of the Arduino, the Arduino and Oscilloscope were connected to one output of a 2 foot sensing section. Using four different scenarios and ten trials each, the mean percent error came out to be 4.14%. The four different scenarios were a walk, two foot jump, bounce and hard hit. With the oscilloscope as the theoretical value and the Arduino as the experimental, the percent error was calculated per each trial. Table 6 shows the mean percent error per each scenario as well as the standard deviation.

| Scenario | Mean Percent Error | Standard Deviation |
|---|---|---|
| Walk | 2.17% | 1.73% |
| Two Foot Jump | 3.77% | 1.9% |
| Bounce | 4.01% | 2.13% |
| Hard Hit | 6.62% | 2.84% |

*Table 6: Results from Testing the Accuracy of the Arduino*

Overall, the results came out better than expected. The percent error was due to the Arduino being skewed by a couple milliseconds. Knowing that a ball and person have very different impact duration times, the couple millisecond variations will not defect the accuracy of the overall system. This is because the range between a ball and a person are a minimum of 100 milliseconds difference (see table 3, page 27).

6.2 Testing the Prototype

The prototype was brought to the Union College Volleyball Gym, the Viniar Center. The Union College Volleyball team tested the line with, again, four different scenarios and ten trials each. The four different scenarios were a run, two foot jump, small bounce and hard hit. The first round of testing did not go well. Every single player that ran over the line created a false positive. There are different reasons for this error. The first is that the prototype cannot possibly be secured on the floor without movement. Therefore, any run that moves the tape can result in a false positive when the tape moves back into position. This is because the force sensitive resistors are extremely sensitive and any movement can cause a decrease in resistance. Another reason the run created a false positive is the heel to toe movement. When athletes run, the heel to toe movement sometimes results in the dragging of the toe at the end of the foot impact. Therefore, if a toe were to drag slightly on

the line it could contact a sensor for a small amount of time. Another factor to consider is the code. For the first part of testing, the ball was determined by a limit in the Arduino code: `if((totalTime1)<100 && (totalTime1)>1`. The lower limit of 1 millisecond is not a good choice. This is because as a run goes from heel to toe, the toe drags on the floor and may have a very small duration of impact. This small impact could create false positives as a player runs over the line. To fix this, the coding limits were changed to: `if((totalTime1)<100 && (totalTime1)>10`. No ball contact that has been measured is faster than 10 milliseconds; therefore the new code will not cut out any ball impact possibilities.

Another issue with the first round of testing in the gym was the recovery time for the FSR's. As the tests continued one after another, the overall system stopped working. Further looking at the system, the reason was because the FSR's needed time to regain their high resistance after continuous hard impacts. When receiving continuous high force, the FSR cannot regain the high resistance in a small amount of time. Through testing, the amount of time it takes to regain its high resistance is 30 to 45 seconds. Overall, this is not a huge issue in the game of volleyball. It is rare that a player or ball would continuously apply force to one two foot sensing area. Therefore, the recovery time is only an issue in testing and not in the long run of the project.

Once the code was fixed and recovery time was acknowledged between each test, the prototype had a percent error of 10%. Using four different scenarios: two foot jump, run, ball bounce and hard hit, and 10 tests each, the system did differentiate between a ball and a person. The 10% error came only from the run, as expected. The error is estimated to be from the line not being securely taped onto the floor. It could not be taped securely because too much tape could affect the FSR's as well as damage the gym floor. The error

could also be due to the wires from the FSR's being outside of the line. Below are two figures showing the before and after impacts of a run and a hard hit.


*Figure 17: Before and After Pictures of a Running Force*


*Figure 18: Before and After Pictures of a Hard Hit Force*

Overall, the results from testing were successful. Going into testing, the goal accuracy was 95% with a 10% leeway for the prototype. After fixing minor details, the accuracy of the system was 90%. This is better than expected for the prototype. The error is also most likely due to the construction of the prototype itself. The high accuracy of the prototype is promising for the future of the system.

## 7. Future Work

The first part for future work is expanding to the whole court. Right now, the prototype is only 6 feet long with three inputs going into the Arduino. A volleyball court has a perimeter of 180 feet, meaning 90 2 foot sensing sections. An Arduino Uno does not have 90 digital inputs; therefore a MUX is needed to handle the amount of inputs. A full court would need six 16 channel MUX's. Some challenges to consider with a MUX are if the Arduino Uno will still work, if the power specifications change, and if the code will need to be altered. Looking at table 2 on page 23, the amount of digital pins the Uno has is 14. In Figure 19, a 16 channel MUX has 4 digital output pins [18]. Therefore, there needs to be a total of 24 digital pins in the microcontroller. The Uno will not work for this system and the Mega will be chosen since it has 54 digital input pins.

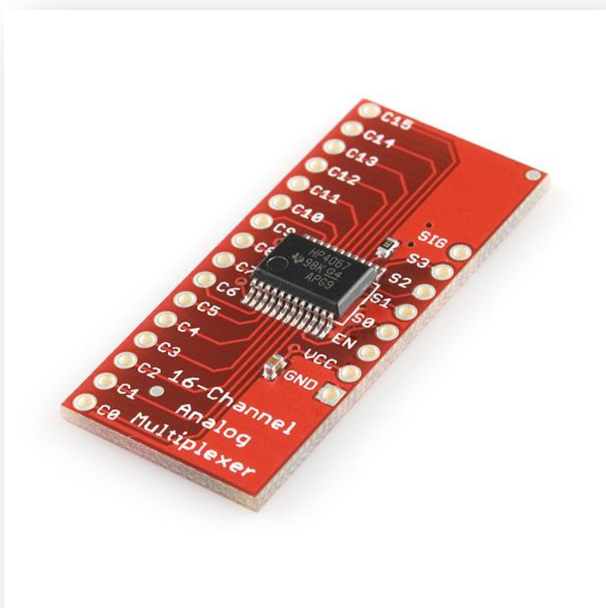


*Figure 19: 16 Channel Multiplexer [18]*

Since choosing the Mega, the power criteria will be changed. The Mega has a current draw of 500mA (see table 2 on page 23) and each MUX has a current draw of 25mA [18]. With these additional factors as well as the increase in the number of sensors, the total battery capacity calculated is 6,827 mAH.

<u>Number of hours needed:</u> 10 hours
<u>Current draw:</u>
Microprocessor: 500mA
LED: 3mA
Op amp (90): 45nA each
FSR's (270): 0.11mA
MUX(6): 25mA
Total consumption=682.7 mA

Battery Capacity/current draw= number of hours

Battery Capacity=6,827 mAH

The battery capacity is very high and therefore a 9V battery will not work for a 10 hour day. Since a 9V battery has a battery capacity of 620 mAH, there would need to be 11 9V batteries in parallel in order to ensure the system works for 10 hours. This seems too extreme and the battery consumption needs to be looked into further in the future.

Lastly to consider when using a MUX is the coding. If using a 16 input multiplexer then the clock timer in the code must be 16 times faster than originally coded. Therefore, instead of using the millis() command, which counts up in milliseconds, then the command micros() will be used because it counts up in microseconds. Overall, when expanding to a whole court the microcontroller, batteries and code will need to be changed.

The second part of future work is to ensure accuracy. Because the prototype was not durable, certain tests could not be done. Volleyball players frequently dive for balls and usually land or slide on the line. Because the prototype was not secure on the gym floor, there was no way to safely test this type of contact. To further ensure accuracy, all possible

body contacts must be tested on the line. Another factor to test is any impact that barely touches the line. It is hard to test such an impact without knowing exactly where the force lands. Another test that needs to be done is a high velocity ball contacting the line at a low angle. Such a ball could possibly roll over all three sensors at different times adding up to a total longer time on the line. This is a possibility that the system could miss the ball contact and not turn on the LED. Overall, further testing will have to be done to ensure the accuracy of the system.

The third part of future work is to confirm that the recovery time of the FSR's will not be an issue in a game. In order to test this, a full court prototype would need to be set up and a game played. Each two foot section would be carefully watched to see the amount of impacts each one receives. From there, a timer should be set in between in each contact in order to ensure that the FSR has enough time to recover from the impact. A success in this test would ensure that this system would be accurate at all times during a game.

The last part of future work is to create a well-constructed final product. The prototype is clearly not constructed well with the wires on the outside of the line and the bottom layer of tape making the prototype portable. Ideally, a 2 inch wide double sided tape would be the bottom layer. The installation of the in and out line monitoring system is another part to consider in the construction of the line. Currently there is no simple way to install this system with the double sided tape, but that is something to look into in the future.

## 8. Production Schedule

Throughout the three term capstone there were different phases of design for this project. During the first term, the main goal was to come up with a project idea and back it

up with research and possible designs. Multiple project ideas were brainstormed and one was picked. Once the project was picked, research was done to gain more information on the problem and possible solutions.

The next term consisted of coming up with a preliminary design. To do this, preliminary tests were done in order to get some limitations on the design. Also during this phase, the Student Research Grant was submitted and accepted. In order to get a grant accepted, research, data and a preliminary proposed design were needed. Throughout the term, the design came together and was defended through tests and research.

The last term was the most difficult. It is where the in depth detail of the design came to be very important. Through each design step, tests were done in order to reduce unexpected errors with the final product. Some parts of the preliminary design were changed according to how the system was coming together. For example, the final prototype of the line changed significantly from the preliminary design adding thickness to the desired product. Overall, the most important parts of the three term process was research and testing. Without preliminary research and testing each step of the way, the project outcome would not have reached such success.

## 9. Cost Analysis

Throughout the process, the budget list changed significantly. The proposed budget in the Student Research Grant, see table 4, changed most during the third term of the project. This is mostly because small components were left out due to the design not being fully complete when the Student Research Grant was due. Table 7 shows the final budget list of the project.

| Stage: | Part: | Purpose: | Price |
|---|---|---|---|
| Force Sensitive Resistors | (9) FSR 408 | Needed to send signal to microprocessor | $161.55 |
| Microprocessor | Arduino Uno R3 | Converts input to output | $39.38 |
| Op amps | (3)LM358 | Part of circuit | * |
| Resistors | (3)820K ohm | Part of circuit | * |
| Resistors | | Part of circuit | * |
| Battery | 9V lithium ion battery | Power for circuit | $3.81 |
| Wires | Soft flex wire | Thin, durable wire to connect components | $11.69 |
| Tape | 3" wide tape | Tape for transportation | $15.70 |
| Tape | 2" wide | Tape for overlaying line for prototype | $6.58 |
| Battery holder | 9V enclosed battery holder with on/off switch | Encloses power for circuit and Arduino | $2.95 |
| Indicator | LED | Provides output for ball contact | * |
| Enclosure | Arduino Uno and Ethernet shield transparent acrylic case | Holds Arduino, solder board and battery pack | $6.95 |
| Cable Sleeving | Smart Power Supply Cable Sleeving Kit | Holds all of the wires together | $9.95 |
| TOTAL | | | $258.56 |

*Table 7: Final Budget of the In and Out Line Monitoring System for Volleyball. * indicates the component will be covered by the ECE department*

Though this final budget did increase from the first proposed budget (see table 4 on page 31), it is estimated that the final product will still be cost effective if mass produced. The most costly part of the system was the force sensitive resistors. If the FSR's were ordered in bulk, the price per sensor would be much less than the unit price shown above. Assuming each FSR would be half the price and adding the extra cost of the Arduino Mega and MUX's, the overall system for a full volleyball court would only cost around $2,300. This price

compared to the Hawk-Eye's price of $400,000 per court proves that the In and Out Line Monitoring System for Volleyball is a cost effective product.

## 10. User's Manual

To use the line monitoring system is simple. The most difficult part is the installation. Assuming a simple way was introduced to roll out the overlaying tape to the boundaries of the court; a consumer just needs to carefully place the overlaying tape on top of the preexisting lines. Once the overlaying tape has been carefully placed over the boundary lines, the controller can be set up at the head referee stand. Simply turn on the "on" switch when it is game time and turn the "off" switch when the line monitoring system is not in use. If used during a tournament weekend, make sure to charge the battery overnight so the system can be used for the full day the next day. The battery life time is about 10 hours. When the line monitoring system is not in use for a long period of time, simply disconnect the device at the head referee stand and place it in a safe area. There is no need to take the overlaying tape off of the floor during other sporting events.

The warranty was not provided on the force sensitive resistor data sheet; therefore it is unknown about the warranty of the monitoring system. The hopes are that it will work accurately for a minimum of 4 years. After the warranty is up, it is suggested that a consumer replaces the overlaying line tape. The other components of the system do not need replacement.

## 11. Conclusion

Volleyball is a fast paced, competitive game and line calls are an issue that continuously comes up in any level of play. Any line judge trained or not, can make an error due to lack of focus, speed of the ball, and inaccuracy of the eye. These calls can be just a minimal point in

a game, or the deciding factor between the continuation of a season or termination of a season. An in and out line monitoring system will relieve the stress of line judges as well as ensure good calls and a fair game for players and coaches.

The line monitoring system consists of force sensitive resistors build into a tape which lays over the boundary of the court. A microcontroller receives a signal from a force and the algorithm decides if the force is a ball or a person. The output is an LED light to indicate if the ball did touch the line.

There were clear goals set for the system that needed to be reached. Tests were done with the prototype to check the accuracy of the system. The goal was to build a system that was 95% accurate, with leeway for a prototype. The results were a success as the line monitoring system only had a percent error of 10%. This error is estimated to be because of the poor construction of the line. Another goal of the system was for it to be safe. Ultimately, the prototype was not the ideal thickness from what was researched for the preliminary design but the thickness did stay within range of being negligible to players. The prototype did fail the goal of being easy to install. There still needs to be some research and thought going into how the line monitoring system can be easily installed into any gymnasium. A goal of being cost effective was also not reached, but it could be in the future. The prototype was costly due to the fact that no products were bought in bulk. If components were bought in large amounts the cost of the system would be extremely effective on the market coming in much lower than the Hawk-Eye for tennis. Lastly is the battery power and use. Although the battery life was not tested, the calculations do conclude that the prototype will run a 10 hour day on a 9V battery.

| Goal | Success? |
|---|---|
| Safety/Flat | Maybe |
| Accuracy/Does it work? | Yes |
| Easy Installation | No |
| Battery/Use | Maybe |
| Cost Effective | Maybe |

*Table 8: Goals and Results Table*

All in all, the In and Out Line Monitoring System for Volleyball was a success. Though not all goals were reached, there is a clear idea of how they can be reached in the future. There is plenty of work left to do on this project in order to create a system that can be competitive on the market. The in and out line monitoring system can revolutionize the game of volleyball and bring the games old fashion techniques into a more modern world.

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## 13. Appendix

A. Arduino Code

```
/* KELLEY WHITE: IN AND OUT LINE MONITORING SYSTEM
 *  TAKES INPUT SIGNAL AND DECIDES IF THE CONTACT IS A BALL OR A PERSON
 */

int ledPIN= 13; //LED connected to digital pin 13
int PIN_D1=12;   //2 ft section to digital pin 12
int PIN_D2=11;    //2 ft section to digital pin 11
int PIN_D3=10;    //2 ft section to digital pin 10
unsigned long startTime1;
unsigned long endTime1;
unsigned long totalTime1;
unsigned long startTime2;
unsigned long endTime2;
unsigned long totalTime2;
unsigned long startTime3;
unsigned long endTime3;
unsigned long totalTime3;

void setup() {

  pinMode(PIN_D1, INPUT);
  Serial.begin(9600);
  pinMode(PIN_D2, INPUT);
  pinMode(PIN_D3, INPUT);
  pinMode(ledPIN, OUTPUT);   //initializes digital pin 13 as led output
  Serial.begin(9600);
}

void loop()
{

    if(digitalRead(PIN_D1) == HIGH) {
      startTime1 = millis();
      while(digitalRead(PIN_D1) == HIGH);
      endTime1 = millis();
    }
    totalTime1=(endTime1-startTime1);
    //Serial.println(endTime1-startTime1);
    if((totalTime1)<100 && (totalTime1)>10) {
```

```
      digitalWrite(ledPIN,HIGH);
      delay(5000);
      digitalWrite(ledPIN,LOW);
    delay (1000);
    startTime1=0;
    endTime1=0;

    }

    if(digitalRead(PIN_D2) == HIGH) {
       startTime2 = millis();
       while(digitalRead(PIN_D2) == HIGH);
       endTime2 = millis();
    }
    totalTime2=(endTime2-startTime2);
    //Serial.println(endTime1-startTime1);
    if((totalTime2)<100 && (totalTime2)>10) {
      digitalWrite(ledPIN,HIGH);
      delay(5000);
      digitalWrite(ledPIN,LOW);
    delay (1000);
    startTime2=0;
    endTime2=0;

    }

    if(digitalRead(PIN_D3) == HIGH) {
       startTime3 = millis();
       while(digitalRead(PIN_D3) == HIGH);
       endTime3 = millis();
    }
    totalTime3=(endTime3-startTime3);
    //Serial.println(endTime1-startTime1);
    if((totalTime3)<100 && (totalTime3)>10) {
      digitalWrite(ledPIN,HIGH);
      delay(5000);
      digitalWrite(ledPIN,LOW);
    delay (1000);
    startTime3=0;
    endTime3=0;

    }



}
```