LASERef

Tim Freitas, EE, Sam Auwerda, EE, Josh Gallant, EE, and Josh Setow, EE

***Abstract*—LASERef is a system designed to mark first downs in the game of football faster and more accurate than the conventional way. LASERef is a break-beam detecting system that can determine if the football has crossed the first down plane on close calls. The system then relays this information along with a picture of the ball on the field to fans and refs via Twitter and a GUI.**

I. INTRODUCTION

THE current first down marking system in the NFL is flawed. The method is slow, inefficient and prone to human error. The following report will demonstrate the design and build of the LASERef, a new and improved way of determining close-call first downs throughout a football game.

The Current System: Once the referee spots the ball on the field, they look to the sideline and attempt to determine whether or not the ball crosses the first down line, marked by 2 markers, one on each side of the field. In situations where the referee cannot make that decision with the football and marker being some distance away, the game is stopped and the markers are brought onto the field for a closer look. At that point, the referee determines whether or not the nose of the football has crossed the marker.

As of late there have been articles commenting on the implementation of lasers and potentially chips inside footballs to solve this controversial situation. Recently, Pro Football Talk published an article detailing the Houston Texans' frustration with a pair of first down calls in their Monday Night loss to the Oakland Raiders earlier this season [1].

Human judgement is something that any sport would love to eliminate. Human judgement brings in the possibility of mistakes and biases. Even with the marker being brought onto the field and placed right next to the nose of the football, there have been mass amounts of controversy on the referee's decision of whether or not the ball has crossed the first down plane.

This is a slow and cumbersome process. With a society obsessed with instant gratification and stimuli that allow for shortened attention spans, a faster method could provide a much more enjoyable viewing experience. As it currently stands sports are moving to reduce the average game time. For example, the MLB is experimenting with a variety of new rule changes that will decrease the average time of a MLB game including the 20-Second rule - allowing a pitcher only 20 seconds between pitches, the Batter's Box rule - prohibiting batters from taking both feet out of the batter's box between pitches, No Intentional Walks, 2:30 Inning Break Clock, 2:30 Pitching Change Break Clock, and Three "Time Out" Limit - allowing a team only 3 times per game to conference on the field [2].

And finally, this process poses as a potential unfair and undeserved advantage to a team. While these markers are being brought onto the field, the clock is stopped, allowing the teams to reconvene, get set-up and make a more well thought out decision on their next play call. A situation where this clock stoppage is especially detrimental to a team is during the "Hurry-up Offense". The goal of this offensive tactic is to play a fast paced game, running play after play in an attempt to both catch the defense off-guard and to tire them out. Having an unnecessary clock stoppage during a "Hurry-up Offense" is an underserved and unfair advantage for the defense.

The LASERef is the solution to all these problems. With the use of lasers, after the referee has spotted the ball, the system can determine if the football has crossed the first down plane with the click of a button. Refer to Table 1 for the specifications of the LASERef.

The first down marking process in the game of football has been a problem for some time. No alternative measures have been implemented into gameplay. An interesting solution to this has been proposed in a system called "First Down Laser Systems" [3]. In this system, a green line is actually projected onto the field at all times throughout a game to signify the first down line.

Specification	Value
Transmitter Weight	1.96 lbs
Transmitter Dimensions	5.5" x 7.5" x 7.5"
Receiver Weight	6.2 lbs
Receiver Dimensions	12" x 5.5" x 13"
Battery Life	~5 hours
Alignment Time	~4-5 seconds
Receiving Distance	< 90 yards

Table 1: Specifications of the LASERef

Specifications were chosen in an attempt at making the system small, lightweight and mobile. The system had to have a battery life that was long enough to endure a full football game and also make it through a potential overtime. The alignment time was measured by taking the average of a variety of attempts at lining up the laser with the receiver from

50 yards away. The receiving distance needed to, at a minimum, reach approximately 55 yards (50 yards across the playing field and at least another 5 yards extra because the markers will not be place directly on the start of the playing field).

A final issue that needs to be addressed is the ability for a fan or team to "hack" our system. This is prevented by a "light shield" that is implemented over the receiver to stop any outside laser or light from causing a faulty reading.

II. DESIGN

A. *Overview*

LASERef is a proposed solution to the current state of first down determination on close calls. The system is essentially a break-beam detector that determines if a first down was made, and then sends that information to fans and refs via Twitter. The system consists of a laser emitter, a photodiode receiver, and a Raspberry Pi computer.

The system is designed to transmit a laser beam from one side of the field to another to create a precise and quick line that marks the current first down location. On close calls after the referee places the football, the system will shoot the laser across the field. If the beam is not broken and the receiver collects light from the laser, then a first down is not made. However if the beam is broken and the football blocks the laser beam from reaching the receiver then a first down has successfully been achieved. A signal LED located on the receiver will illuminate letting the chain crew know if the beam has been broken, and hence a first down has been made. This information can then be immediately uploaded to Twitter and a GUI using a button on the marker. This entire system is highlighted in Figure 1.

The entire system is designed to be an unobtrusive improvement to the game. The receiver is built into the already existing poles that are used to mark the first downs and the transmitter is planned to be installed on first down marking matts as well. The receiver and transmitter were also constructed so that the chain crews who manage the first down markers could easily move and do their jobs without new complications.

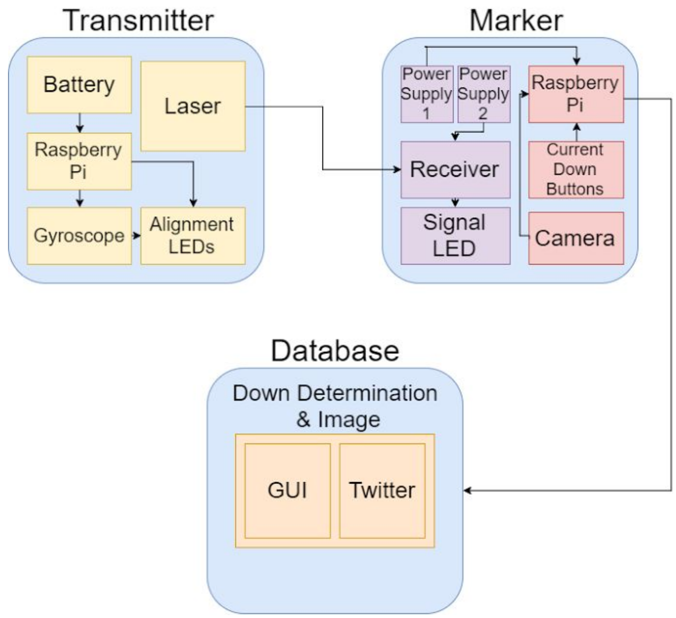

Figure 1. Block Diagram

B. *Receiver*

The receiver in the system was designed using a photodiode. The photodiode works by creating a higher current across itself when it is excited by incoming light. This increased current is then used to send other signals inside of the receiver.

However, building the receiver isn't as simple as a photodiode alone connected to a battery. The photodiode needs to be sensitive to the beam of light being shot across the field. The photodiode also needs housing to block any unwanted light from the outside that might excite the diode when it shouldn't be excited. The housing for this photodiode also needs a way to channel the light to the photodiode to make sure that it's getting enough light to produce enough current.

The laser that is used for the transmitter is a high power 5mW laser that emits a beam of light at 532 nm wavelength. This wavelength is important because it is a very big influence on the photodiode that is used in the system. As shown in Figure 2, a Vishay BPW21R Photodiode is used [4].

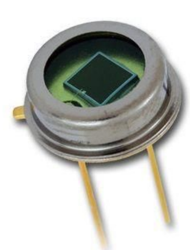

Figure 2: Vishay BPW21R Photodiode

This photodiode was chosen for two main reasons. The first is because it is able to operate effectively between -55°C and +125°C which means that it will be able to function in all temperature ranges that football is generally played in. The second and most important reason is that it's peak sensitivity is to light at 565 nm wavelength. Figure 3 shows the spectrum of light that this photodiode is sensitive to.

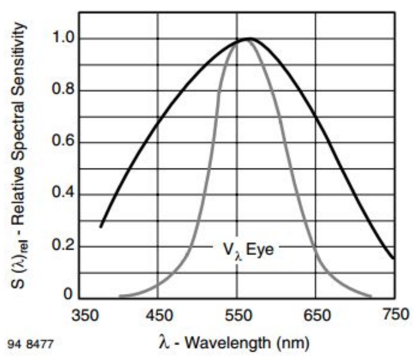

Figure 3: Relative Spectral Sensitivity vs. Wavelength taken from Vishay datasheet [4]

Considering that the transmitter laser in the system emits light at 532 nm, this means that the receiving photodiode is very sensitive to the laser transmitter and can easily be excited by the laser.

In addition to simply choosing an applicable photodiode to use to receive the light, the actual size of the diode itself needed to be taken into consideration. The photodiode is only 5mm in diameter. If the photodiode was used alone to receive the light from the transmitter, which is 50 yards across the field, the laser would have to hit a tiny circle that's only 19.6 square millimeters. Accomplishing that would be nearly impossible so the receiver is designed to direct light toward the photodiode and give a bigger area to hit. A reflective cone with a diameter of about one inch is used to surround the diode as shown in Figure 4. When light from the laser hits anywhere inside of the cone, the reflective material reflects the light all throughout the inside and excites the photodiode. This gives the laser a slightly bigger area to hit and makes it easier to excite the photodiode from across the football field. This design was chosen because it was an effective method of exciting the diode and it was simple to build.

Figure 4: Cone - Photodiode Receiver

C. Receiving Circuit

The receiver circuit makes use of a photodiode, comparator, rectifier, inverter and an LED. Refer to Appendix A1. In general, when the photodiode is excited by the laser, the LED is not illuminated. When the photodiode is not excited by the laser, the LED is illuminated.

When the photodiode comes in direct contact with the laser it generates a square wave with a peak to peak voltage of ~5.5V between 0V and 5.5V. This is a square wave due to the fact that our laser is shooting at a frequency of about 150 Hz which is unnoticeable to the human eye (This was discovered by shining a light at the photodiode and observing that the received signal was a flat voltage signal). This voltage can vary slightly due to the laser not directly striking the center of the photodiode or the laser reflecting off our reflective receiver and into the photodiode. Due to this, the square wave is first sent through a comparator (LM339) [5], comparing to a reference voltage of 500mV. This outputs a perfect square wave between 5V and 0V. The reason 500mV was chosen was to maximize the sensitivity of our system (Laser does not need to directly strike the center of the photodiode) but also to eliminate the possibility of ambient light from triggering the LED.

After the comparator, the square wave is sent through a rectifier. In this circuit the rectifier is simply a diode in series with a capacitor going to ground. The output of this is a 5V steady signal. How this rectifier works: The square wave is sent through a diode. A diode is a non-linear device that only allows current to flow through it in one direction. When the square wave is high (5V) the capacitor charges up to 5V. When the square wave is low (0V) the capacitor discharges it's 5V. This happens repeatedly and results in a steady 5V signal. Because a diode was used, the discharging cannot pass back through the diode and the output receives all 5V that is being discharged.

Finally this 5V signal is passed through an inverter (CD4049UBE) [6]. In this implementation, the LED is illuminated when the photodiode is not illuminated, so at 0V at the output of the rectifier the LED should receive 5V and at 5V at the output of the rectifier the LED should receive 0V.

Refer to Figure 5 for the output of the receiver circuit when the laser beam has been broken.

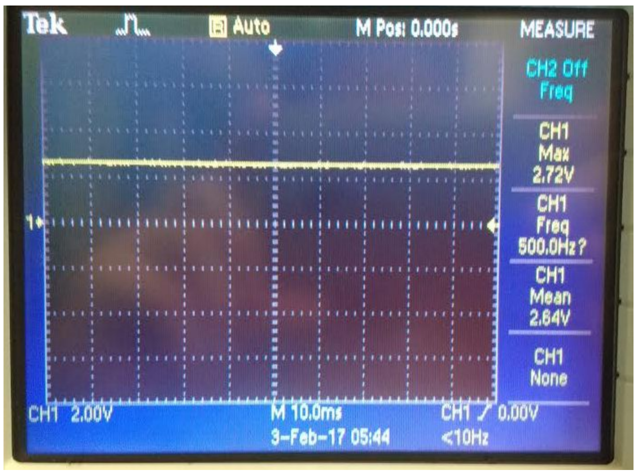

Figure 5: Output of Receiving Circuit When Beam is Broken

This circuit was then implemented on a PCB (Printed Circuit Board) as shown in Figure 6. The PCB is a 2 layer board that is 2.09 inches x 2.20 inches. It was ordered from OSH Park.

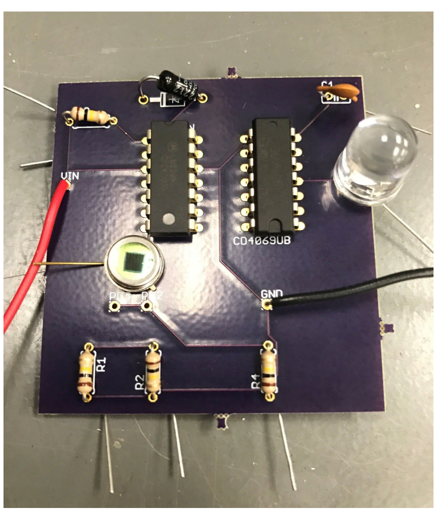

Figure 6: Receiver Circuit on PCB

The receiver circuit is powered by a portable rechargeable power source, similar to one you would purchase to charge your cell phone on the go. We purchased a power supply module for a breadboard, shown in Figure 7, to convert the power sent through a USB to 5V pins that could be used to power a breadboard. An issue we encountered was that the power supply was not sensing a large enough load and actually turning off automatically after about 30 seconds. The way in which we fixed this was by simply putting 5 resistors in parallel to increase the load.

Figure 7: Breadboard power supply module

D. Transmitter Box

The purpose of the Receiving Box block is to have a physical structure that can hold all the devices and circuitry needed for our first down determination system to work. A main objective for this block to have a structure that is sturdy while being unobtrusive to the game.

The Receiving Box contains a photodiode, a signal LED, the receiver circuit board, two power supplies, a Raspberry Pi, a camera and a button strip labeled 1-4 to coincide with each down in a football game. ¾" thick pine was chosen as the material used to build the structure as pine is sturdy, lightweight, and inexpensive. For easy mobility, the structure had to be connected to the first down markers.

The Receiving Box was redesigned to sleeker and more visually striking box with dimensions of 12" x 5.5" x 13" (first design: 10" x 6.5" x 14.5"). We also replaced the large obtrusive battery that we had placed on top of the box with a smaller rechargeable battery (portable phone charger, one used to charge Raspberry Pi and one used to charge the circuit).

Figure 8: Receiving Box Design

A common problem we encountered in our project was ambient sunlight tripping our photodiode sensor and giving a false reading. This was the reason we increased the width of the box by 2", so the photodiode was further back in the box and less likely to be tripped by sunlight.

Figure 8 shows photos of the receiving box design from the side and front, respectively. This box design was compact and optimized spacing. Foam tape was used to hold the devices inside in place. A 1" wide hole was cut in the front part of the structure to allow the photodiode receiver to stick out and pick up the transmitted laser. The center of the hole is 3.9" off the ground. Our first down detection system is currently designed to work for a junior size football, which has a radius of 3.9" [7]. Three light shields, made out of PVC pipe, was added to the box to surround the receiver to help with the aforementioned sunlight problem. The logic with the light shield is that it will prevent the sunlight from getting into the reflective cone while additionally preventing any fan in stadium with a laser of their own from using it to sabotage the system as the light shield will limit the photodiode to only picking up a laser from the sidelines. The PVC pipe was also painted black to absorb sunlight rather than reflect it and possibly result in false readings. Also a filter, in our case just a stretched piece of paper towel, was glued to the front of each PVC pipe which helped with restricting sunlight but not restricting the laser from exciting the photodiode from 50 yards away.

Inside each light shield is a photodiode. The reason for the additional two was to minimize alignment time. As long as the transmitter was perfectly aligned, 10 yards down the field from the ball than the receiver box would have some room for error. Instead of hitting a 1 inch diameter hole, it can hit three 1 inch diameter holes.

The box was also painted orange to coincide with the color of the first down markers and also padded. The padding serves 2 purposes; most importantly player safety but also for the safety of the receiving box itself.

E. Software

The software portion of the LASERef system is split into two portions: The Raspberry Pi and the Graphical User Interface (GUI). The Raspberry Pi inside of the transmitter is connected to the 4-Button strip for each down that the user can press. When the user presses one of the buttons, this information is sent it to the Raspberry Pi through various GPIO pins. GPIO pins are the metallic pins that are lined on the board. As seen in Figure 9, they contain input and output pins as well as ground and power. The Pi automatically runs a script, written in Python, which makes use of these pins. When a pin receives an input, we can write a line of code that will perform an action. This was initially tested with an LED on one of the output pins. When the input is received from the switch, the LED would turn on and when there is no signal to the pin, the LED would turn off. After testing with the LED, we knew that the pins were function properly and we could implement the Twitter.

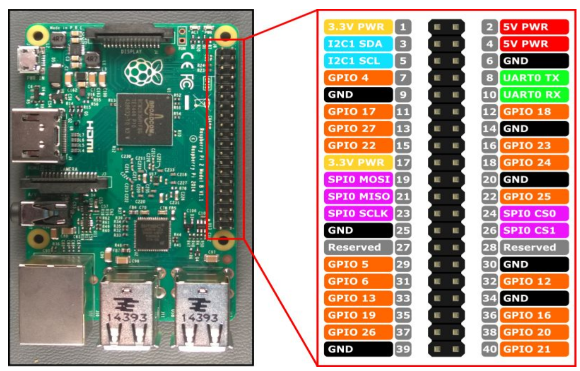

Figure 9: Raspberry Pi GPIO pins

As mentioned previously, the python script run on the Raspberry Pi makes use of Twython [8], which is a user-developed Python package that makes use of Twitter API to access core Twitter mechanics via Python script. The requirement for Twython is to register a "Twitter App." A Twitter App gives the user a series of serial keys which, when used properly, allow you to access the Twitter account without the need for logging in. The Twython package uses these keys to send Tweets via one line of Python code. By adding these lines of code into the Python script, we can send Tweets to Twitter when an input is received to the designated GPIO pin.

Finally we also hooked up a web-camera to our system. This camera is connected to the Pi via a USB port and was implemented in the Python code. The final script, upon pressing either 1, 2, 3, or 4, will automatically take a snapshot with the web-camera, of the ball on the field. It will then, via Twython, send a Tweet to our Twitter page with the corresponding down, game time, and picture of the ball on the field. An example can be found in Figure 10.

Figure 10:: Screenshot of Tweet

For the Raspberry Pi to work properly and connect to Twitter, it needs to be connected to the internet to work and since our project needs portability, we had to rely on Wifi. On the UMass Amherst campus, there are two Wifi connections that students can connect to: "UMASS" and "Eduroam." The UMASS Wifi is the less secure Wifi and in order to connect to it, a student must load a webpage, be redirected to a login page, and enter their student credentials. This must be done each time the student wishes to connect to UMASS. With our system we need to be able to connect to Wifi automatically upon startup and plugging in a computer monitor and keyboard and typing in the credentials for UMASS would be very inefficient and a waste of time. Therefore, we had to reply on Eduroam for this to work. For any system to connect to Eduroam for the first time, a user must install a program called XpressConnect. XpressConnect automatically configures your computer/phone to be able to connect to the Eduroam network. This program was not available for use on a Raspberry Pi, so we had to manually configure the Pi to automatically connect to Eduroam. This was done by editing a text file called "WPA-Supplicant.conf." This is a text file on the Pi that contains information about all of the surrounding Wifi connections. The information for Eduroam had to be manually entered into this text file along with a student's credentials. Essentially by doing this, we did all of the things the XpressConnect would normally do, just done manually. We were able to do all of this via a tutorial we found online [9].

Finally, we also developed a Graphical User Interface (GUI) on a computer. The GUI was developed using Java code in a program called Netbeans [10]. Netbeans is an applications that allows a drag and drop interface to build the program. The GUI in it's final state launches a splash image with the LASERef team name and then enters the main interface. The application has one screen which shows the team name, as well as a text box for the current information and the most recently captured image. The GUI interface works by loading our Twitter page in the background and extracting all of its contents. It then displays the current down, game time, and the image of the ball in view. A screenshot of the GUI can be found in Figure 11.

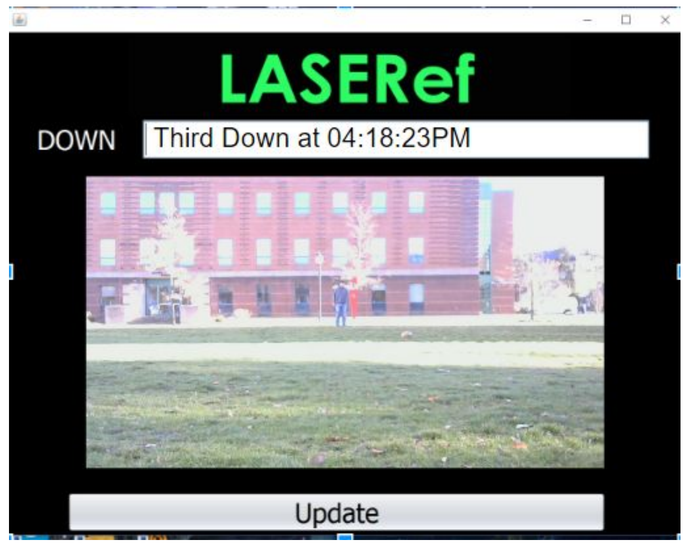

Figure 11: Screenshot of GUI

The benefit of relaying all the information to Twitter was that anyone could access the information anywhere. This made it much easier to troubleshoot our project. In addition, during a game, anyone who would need the information could access it in real time without waiting for the referees to make the call. People, such as fans and coaches, can all open up the Twitter page and check to see in real time what the status of the system is.

F. Transmitter

The transmitter is placed on the opposite side of the field of the receiver. Its main job is simply to beam the laser across the field in a straight line that accurately represents where the first down line should exist. There were two main issues we wanted to address when making the transmitter. First, we wanted appropriate housing for the unit. Something that could be light and small enough so it was easy to carry, and something that could easily fit all of its components and protect them well enough from the average football game. The second issue, and very big issue we wanted to address was making sure that our laser would be aligned with the receiver on the other field, and making this alignment process much faster. The last thing you would want when using our system is to have the laser beam to be askew across the field and not accurately measuring a first down. We wanted to avoid this.

The transmitter itself when completed was made of 3D printed box, which housed and rechargeable battery, the 5mW transmitter laser, and a raspberry pi that we used for alignment. We used a 3D design and modeling software called Tinkercad to design the box. Since a 3D printer has issues with printing out designs with overhangs we needed to design the box in separate files. For example, the cover of the box was designed upside down for the reason that it would be difficult to print floating parts without a base. Figure 12 shows the designs for the base of the box and cover of the box. When printed out, those separate parts were then glued together with Gorilla Glue to form the 3D printed transmitter box. The dimensions of the box came out as 5.5" x 7.5" x 7.5." The box came out to be extremely sturdy as the walls of the box were designed at 0.125" thick. A good sturdy box is needed as this box needs to withstand a potential collision with a football player during a game. In addition, to lessen injuries when those instances do happen we added foam padding to the sides of the box.

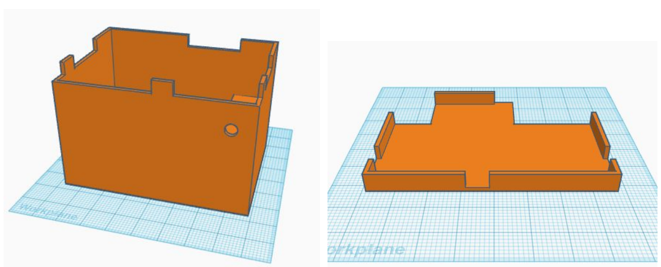

Figure 12: Base and cover designs of 3D printed transmitter box

The alignment issue was solved with a Raspberry Pi and an LSM9DS0, a chip equipped with a gyroscope, accelerometer, and magnetometer. The LSM9DS0, as shown in Figure 13, was setup to communicate with the Pi and send over information from the gyroscope on the chip. The Raspberry Pi ran a script on startup and ran it continuously while it was powered to extract information from the gyroscope on the chip and send it to the Pi for analysis. With a button attach to the Pi, one could press it and create what we referred to as a "save angle". This would take the current readings from the gyroscope and set it to a variable within the script. The script would then set a tolerance to this angle of about 0.7 degrees in each direction. If the save angle was set to 35 degrees, then the region of acceptance is about 34.3 to 35.7 degrees.

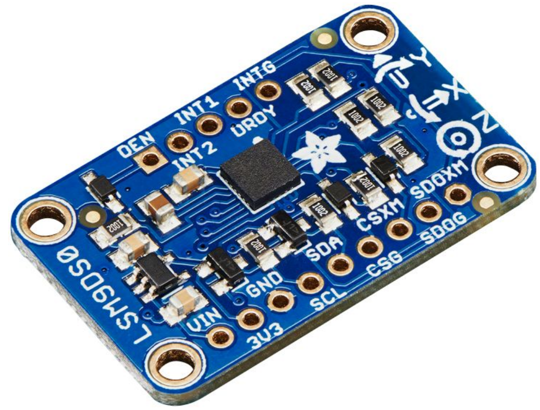

Figure 13: LSM9DS0 Chip

The whole point of using the gyroscope in this manner was to make sure that the transmitter would never turn too much out of a specified range so that the laser would be skewed. The idea is that you would calibrate the save angle before the game started. You would make sure you're as straight as you could be across the field from the transmitter and hit the save angle button to remember that angle. Then, during the game as you brought the transmitter up and down the field, the transmitter would warn you with LED indicators on the outside of the box if you turned the box too much so that you have deviated outside of the tolerance of your save angle. Figure 14 details the transmitter box with the alignment reset button and the indicating LEDs.

Figure 14: Transmitter Box with Alignment button and LEDs

This method is not perfect because the LSM9DS0 was only so accurate, we could only make our tolerance to around 1.5 degrees. This doesn't sound like much, but if this was to be projected all the way down to the other side of the field, 50 yards, then you could potentially have the laser be skewed by 1.3 yards in the worst case scenario. Because of this, the gyroscope alignment technique was used to assist in the alignment process to make it faster and more accurate. It was designed to help the operator aligning the laser easier, but the process was still left up to human operation and using their own eyesight to make sure the laser was aligned.

G. Project Management

FPR Deliverables
New housing units for the transmitter and receiver
Improved materials for light shield
Improved accuracy on the angle detector
Test and collect data

Table 2: FPR deliverables

Our FPR deliverables are presented in Table 2 above. All of these goals were successfully accomplished in our project. As mentioned before, we designed newer and more optimized housing for our transmitter and receiver boxes. We added a light shield to the final receiver box that could block out the sun from hitting our receiving photodiodes in certain situations, but still allowed the laser to get through. Our original cone around the photodiode receivers are still present, but the light shield allowed for keeping ambient light out more efficiently. We also improved the accuracy on out angle detector through the gyroscope. When it was first designed it was accurate to around 3 degrees, but that was cut in half to about 1.5 degrees. And finally we did some testing and data collection where we brought it to different fields and locations to find out where it would work best and be the most successful.

Each member on the LASERef team has contributed important and significant aspects to the overall project and has a specific expertise. Joshua Setow designed the blueprints for the receiver and transmitter boxes. Sam Auwerda designed the angle detector used for alignment. Tim Freitas constructed the receiver box and designed the PCB board for the photodiode receiving circuit. Joshua Gallant updated the Python script for the Raspberry Pi and added the capabilities for it to take pictures as well as connect to the Eduroam Wifi. He also developed and GUI to display this information as well.

Although each team member had their own contributions to the project, everyone helped out to make sure that the goals that had been set were met. When it came to designing the receiver circuit and evaluating different receiver designs, everyone helped to build and test different aspects of the designs to make sure that they could function optimally and successfully. Whether this meant helping to troubleshoot circuit problems or helping construct different materials, the team was there to help when needed. Even for the software aspect, everyone inputted their ideas on how it should work and did what they could to make sure we had the right resources and materials. Although we divided the project up to be done by different people, it was really a group process to make it actually happen.

III. CONCLUSION

For future iterations of the LASERef system, many improvements could be made. One of the issues we had with our system is that it does not always work properly in direct sunlight. The photodiodes, which were designed to get tripped by the laser, can also get tripped by the sunlight. This can make it seem like the ball did not cross the line because the laser was still hitting the receiver, when really it is just sunlight that is activating the photodiode. For future iterations, the LASERef could fix this problem to make it more accurate. One way to fix this would be by attenuating the receiver to only activate when the photodiode receives a pulsing laser. The laser we purchased sends out photons in a square wave (i.e. it pulses). The photodiode could be changed to only activate when it receives this pulse and not from constant light such as the sunlight. Another thing that could fix this problem would be by adding some sort of filter in front of the photodiode to block the sunlight. We tried this, using a paper towel filter, which did not prove to be as effective as we had hoped. A future team could find a better material which could block out the sunlight while still allowing the green laser to pass through.

Another aspect of the system that could have been improved was the angle detector accuracy. As mentioned before, the angle detector had an accuracy of about 1.5 degrees, if we could have used a chip that could have given us more accuracy we could have tightened this tolerance and had a much more accurate designed. We also received suggestions of maybe adding the laser to a servo, so that the laser could automatically set itself to the save angle rather than needing a human to try to line it up by hand.

Another improvement that could be made to LASERef is a more reliable Wifi source. An issue we kept having as a team was the the Pi would keep disconnecting from Eduroam. This would mean that we would keep having to wait until it was reconnected until we could use our system again, sometimes even needing to restart the system entirely. A solution to this problem could be removing the Twitter entirely and only using a GUI so that Wifi would not be need at all. That way the system will never randomly disable after disconnecting from Wifi. A drawback to this would be that fans cannot see real-time updates on Twitter. However the benefit of having an system that is always working heavily outweighs that.

One major drawback of the LASERef system is that it can only work on flat turf fields. Since the laser needs to shoot directly at the photodiode without anything blocking, we found that the system could not work where grass may be long or where the surface of the field is not flad. Our system right now is only meant to work in NFL football games, with flat, turf field. If this system was meant to ever be commercialized, it would need to work on other games of football. A future LASERef team could update the system so that it can be used anywhere regardless of what field the game is being played on. This would be great because then our system could target a wider audience rather than just NFL football games. Anyone who owns the system could use it in a football game in their backyard.

With our LASERef system complete, we feel we have achieved all of the goals that we hoped to complete. We have a fully functioning system that works the way we hoped it would work. As mentioned above, there are some things about the system that could be improved, however overall we are very happy with how the system came out.

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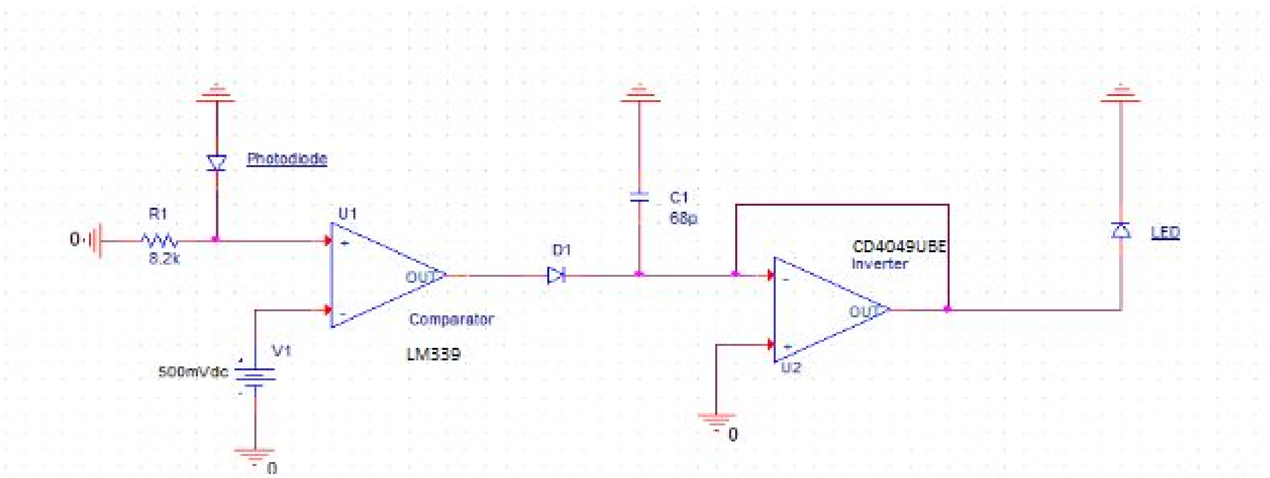

Appendix A1: Photodiode receiver circuit