UCF Senior Design 1 Divide and Conquer Document

Neon Knights
Group A

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Table of Contents

Figure Index

Table Index

1.0 Executive Summary

Neon Knights is an advanced laser tag system made to beat competitors in the laser tag market. Laser tag is a safe real-life player vs player shooting game where the objective is to shoot the opponents before they shoot you. This game is played with handheld devices that look similar to guns called phasors. These phasors mimic the action of shooting a real gun but unlike real guns that shoot harmful bullets, phasors emit harmless infrared lasers. These infrared lasers shoot a beam of focused infrared light that is invisible to the naked eye and when aimed correctly they are meant to hit or more realistically tag opponents that is why it's called laser tag. To detect if the infrared laser has hit a player they wear infrared sensors that send a signal out if they have been tagged. These Sensors are attached to a vest and each sensor is placed strategically in spots like the chest, shoulders, and back to increase the chance of registering an accurate hit and lower false hits.

This concept of infrared technology is incorporated into a fun and safe player vs player shooting game that involves using many skills like hand-eye coordination, strategy, and teamwork to tag your opponent and win the game. This game can be really simple where it's just a gunfight and you need to tag your opponents but there are endless game modes and possibilities that can be integrated into laser tag to make it more fun. These game modes are imperative to the game of laser tag as they make it more fun by forcing players to use more strategy and movement which leads to more and better combat scenarios. We intend to implement things like game modes, reload systems, and other features to make our game more fun for its users. This will make our project better than others on the market by targeting these features.

In our project, we will have to design two different things a phasor and a vest. These will both be completely separate designs that will use wireless communication to connect to a master terminal. This terminal will be a control system connecting every component and will be able to record and display all of the game statistics received from the phasors and vests. These statistics will tell people watching the game and the players after playing the game everything they could want to know such as kills, deaths, points, hit percentage, and much more. This will help the overall functionality of the game and show the players what happened throughout the game.

Understanding how the game will operate from the perspective of the user is important but to build the project you must know how it works from the inside. The two parts of this project the phasor and vest designs will each have their own components that must be produced. Both of these designs however will all connect together through a specially designed printed circuit board with an ESP32 microcontroller. The phasor will consist of multiple parts such as an infrared emitter, an optic lens to focus the infrared light, buttons for inputs such as the trigger, vibration motors, LEDs, and LCD to show in-game statistics. The Vest will contain infrared receivers to detect if hit, vibration motors to signal a hit, and LEDs to show team color.

2.0 Project Description
In this section you will learn about the basics of laser tag, the background of laser tag and how it came to be, the motivation behind why we chose this project, similar projects and products like ours, how ours will be different from them, the goals and objectives we plan to accomplish throughout this project, the specifications we will strive to achieve, and the house of quality showing what we plan to improve. This will tell you everything you need to know about our project, why we chose it, and specifically how it will work.

2.1 Introduction
Our project Neon Knights is a laser tag system but with added features and our own which we intend to implement to add a spin on the traditional game. We gathered many different aspects from other similar laser tag systems and decided on an overall system that would prevail above other products. But within this project we will consist of the basic systems that allows the user to experience a simple game of laser tag, such as an infrared laser system, shooting mechanism, and multiple users. Each systems consist of many different components working together as a group to create a simple game of laser tag. And now that you know the concepts of the game laser tag and a basic understanding of our goals with our laser tag project, you will still need to understand how we intend to implement it and add our additions to a working laser tag system.

2.2 Background
Many historians believe that engineering is one of the oldest professions to exist. Engineering can mean many things throughout history but one thing for certain is that it has been around for a very long time. Engineering started with the very basics of building useful things like tools or the wheel and this eventually started to get more advanced and we started making things like pulleys, levers, and the fulcrum. Although these engineering inventions seem harmless and beneficial for humans some if not most engineering creations aren't always positive and are made for other reasons. One main purpose engineering innovation is used for is warfare as whoever holds the newest engineering technology whether it's a bow and arrow, a trebuchet, or even a highly advanced military plane is the most powerful. One invention that revolutionized warfare was the gun or rifle which was used to shoot metal at high speeds from a distance towards an enemy without having to get close.

Although military weapons are one of the main engineering purposes not all engineering is bad and some very useful things can be invented. Although it took a long time to get to where it is today in the 1800s one invention came to life the infrared sensor. Around this time humans began to experiment with infrared radiation and its capabilities using it mainly for thermal detectors. These detectors became more advanced throughout history and finally in the 1940's the first working infrared detector was invented. The technology for the more modern infrared sensors was only able to come into existence after the invention of the transistor in 1947. After this in 1966 Texas Instruments created the first forward-looking infrared sensor which was the entrance to the modern world of infrared technology. After that technology took over and the infrared sensor became modernized, and slight improvements have been made until today's time when infrared technology has many possibilities.

Another invention that was engineered into existence was the light amplification by stimulated emission of radiation or what most people call the laser. In the early 1900s, the beginnings of laser technology were coming to life but only in theory. In 1917 theoretical foundations on lasers were being conceptually established by no other than Albert Einstein one of the world's greatest physicists, scientists, and some would argue engineers. The first laser was officially built in the 1960s by Theodore H. Maiman he developed this based on previous theoretical work at Hughes Research Laboratories. Since then laser technology has advanced exponentially being used in so many fields like the medical field for surgery, manufacturing to cut shapes, and even something as simple as a barcode scanner at your local grocery store. The use of lasers has become readily apparent in today's world as it is constantly being used, researched, and upgraded daily. One type of laser commonly used is the infrared laser which is super important in the world of lasers because it is unable to be seen by the human eye.

In the late 1970's the United States military decided to mix the warfare of a gun with the technology of infrared lasers and sensors to create the multiple integrated laser engagement system called MILES. The MILES program was designed to recreate as close as possible a hyper-realistic tactical training system in a safe environment. To do this they simulated weapon systems that comprised 11 systems including rifles, tank guns, and missiles. The military kept making more modern versions of the MILES system as time went on including many features one in particular being to make sure that when players are hit they are actually out of the game and no longer able to shoot or as some would say dead. The entire purpose of this advanced military training system was for soldiers to run simulations in a safe environment to practice and get better at their gun skills to prepare them for real-life field combat.

Although this miles system was used in the early 1970s laser tag was not yet commercial at that time. The first commercial instance of laser tag was in 1979 when the film company Star Trek made a toy phasor gun with an infrared laser and sensor. Not long after that, the first laser tag arena opened in Dallas Texas in 1984 starting the national trend of laser tag arenas. Laser tag only got bigger and bigger from there "In 2020 the United States laser tag industry generated an estimated revenue of $315 million". Laser tag is a giant industry with many purposes it can be used for anything from advanced military training, to indoor arenas at your local mall, to a toy that children use. The background behind laser tag may come from warfare roots but no matter what its purpose is used for now it's a pretty fun game to play with friends.

2.3 Motivation

Now that we know the history behind laser tag and how it came to be we can talk about the motivation why we chose this project. In senior design, we are tasked to create a project that has many engineering requirements, so when we began thinking of projects we started with the basics of what are the engineering requirements for this project. We knew we needed to include multiple things like a printed circuit board (PCB), a microcontroller (MCU), a power supply, hardware implementation, software implementation, sensors of some sort for Input, and some sort of output. Although these are not all required and many more things may be required these were some of the thoughts we had when thinking of a project to build. With keeping all of these requirements in mind we began to have a very long list of possible projects to build but something felt like it was missing. We kept brainstorming on projects that would fit these engineering descriptions but for some reason, we were indecisive and kept coming up short.

That's when we got together as a group and decided we needed to add another requirement to our project to help filter out the bad projects we were less interested in designing. One requirement our group added was the project should be considered fun. The requirement to make our project fun was imperative as having a project that the group is interested in building promotes more work to be completed. That's where we started thinking and we landed on laser tag because it fits the requirements of the engineering side while also fitting into the fun category. This is a game that involves almost all types of skills and challenges; it requires physical activity, hand-eye coordination, and strategy. Another reason laser tag is so great is because of its age inclusiveness, social interaction, and competitiveness. These attributes and the skills involved make it the perfect game to play with friends. These reasons make it such a fun game to play which in turn is the reason we believe it will be a fun game to build.

We decided to pursue laser tag for our senior design idea because it fit all the hard requirements set by the professors and it fit the soft requirements we set. Although one of the main soft requirements we set was that the project had to be fun, many other requirements were imperative for our design. One of these soft requirements we liked in our idea was its changeability of difficulty involving the project's functionality and goals. This means if we are struggling with the project we can keep it very simple by just making a basic laser tag system but if we find the project easy as we do more research we can implement an endless amount of ideas to make the design fit the perfect difficulty. This can give our project unlimited possibilities as we can implement upgrades to the system as we desire to make the game of laser tag more fun for its users. Another requirement we had was its demonstrability as we need a project that is easy to display to whoever is reviewing the project. We also wanted a project with good testability in this design we can test each part and each system as a subsystem before we implement the project altogether. This can help because if we test each subsystem beforehand we won't need to put everything together towards the end of senior design and hope that nine months of effort will work. With all of the hard and soft requirements being met, laser tag was the perfect balance and our team is extremely motivated to design this project.

2.4 Project Function

The main game of laser tag is usually played with two main components: a gun or phasor and a vest or sensors, although often these components are all connected via a wire. The gun or as some like to call it a phasor for a more futuristic sci-fi theme is fundamentally a device made to shoot a series of infrared light pulses in rapid succession for each shot. The vest is essentially a bunch of infrared sensors attached to a vest that is meant to detect the infrared laser from the phasors. In our design, we plan to separate these two components to build a separate gun and vest that will connect wirelessly and have their internal parts functionality still work together seamlessly.

2.4.1 Phasor Function

First, we have the phasor or laser tag gun which will have plenty of components that will function on their own separate from the vest. The gun will be built around a printed circuit board which will connect to the microcontroller and all of the hardware parts including the inputs and outputs. These inputs and outputs will all be regulated and controlled by the microcontroller and the code that is written on it. Some of the inputs and outputs that will be connected to the printed circuit board and controlled by the microcontroller would be the infrared emitter, power source, LCD display, trigger, led lights, reload system sensor, wireless communication module, and maybe a knob for some input changes. These components will all be used to control how the phasor functions and will fit inside a 3d printed gun/phasor model.

Inputs are super important in the phasor design as the phasor will rely on inputs such as the trigger, knobs, reload system, and power source. The trigger will connect to the microcontroller and using software the input from the trigger will send specific bursts for the output to control the shooting. This can be implemented together with a knob or input to control the exact bursts with the trigger like single shot, automatic, or even burst mode. Using the trigger and knob and some code ran through our microcontroller we will be able to translate each trigger push and release into the accurate laser output required. One example would be single fire if the knob is set to the single fire setting we need to only send out a laser shot when the trigger is pressed so holding the trigger down will not do anything. This in turn will give the users multiple burst options to choose from when playing the game of laser tag which is an extra feature that normally doesn't exist in laser tag systems.

A shooting game wouldn't be realistic without ammunition or you would be able to shoot forever so we plan to implement an input for a reload system that will give you more ammunition after you reload the gun. This will be like a magazine on a real gun where when you reload the phasor can sense the input and then virtually fill the user's ammunition back up so they can keep firing. The entire phasor will be powered by one source this could consist of a battery and a voltage regulator or a few AA batteries in series. This power source has many requirements and is crucial to function correctly or it could damage the other components or even the users. The power source must output a minimum of 7 volts to power the entire system and meet the microcontroller's minimum voltage requirement. This power source will be able to provide sufficient power for the gun's systems for at least one hour of playtime.

These inputs would connect to the outputs involved in the gun which could include the infrared emitter, wireless communication module, LCD Display, and RGB LEDs. The infrared emitter will be the main output and when the trigger is pressed it will emit a short series of multiple infrared light pulses in rapid succession which will mimic a singular shot these pulses are needed to increase accuracy and hit rate. The infrared emitter has many requirements it must follow in order to be picked up by the sensors. The Emitter must be able to emit infrared light roughly at a wavelength of 940nm and up to around 40m in any type of bust or pattern required by the settings. Each Microcontroller must be able to communicate together which is why one of the outputs and also an input is the wireless communication module this will be able to connect to each microcontroller and help them communicate with each other.

Now that we have covered some of the outputs of the gun that isn't visible to the players there are other outputs designed to be specifically for the player's visibility to enhance the gameplay experience. RGB LEDs will be fitted across the phasor and be able to light up different colors which could show the users multiple things that are involved in the gameplay. Some examples that the LEDs could show players is that it could show the team color or blink red if you have been hit to show you are out of the game. Another really important output is the LCD display which could show the player information and statistics about the game while it's running. This display can so many These were just some of the basic inputs and outputs that our phasor gun could encompass but many more features could be added. This display can show players how many points or eliminations they have depending on the game mode. It can also show a player's health and ammo count to help the players keep track of how they are doing in the game. The display can show all kinds of things and we plan to have it display whatever is most important for the players to be able to see. These were just some of the basic inputs and outputs that our phasor gun could encompass but many more features could be added.

2.4.2 Vest Functionality

Secondly, we have the vest which is a separate design and will have all of its components connected through the vest. This vest will contain less input and output than the phasor but it's still a very complicated design because we need to make sure it is easy to wear, safe, comfortable, durable, and all while being fully functional. On the vest, we will attach using velcro or some glue multiple infrared sensors in specific locations these sensors will have wiring that runs through the inside of the vest to connect with the other components. We will also be attaching haptic feedback motors which will add a vibration effect to signal to the user they have been hit. That combined with LED strips that will be attached along the vest to light it up will be the main visible features of the vest which will all connect through the inside of the vest to the printed circuit board. The other components that will make up our vest will be all packed together in a durable container that will be attached to the upper to the middle back area of the vest. In this container, we will have the wiring from the LEDs, sensors, and haptic feedback motors run into a printed circuit board that will connect to a microcontroller and its wireless communication module to be able to communicate with the other devices all of which is being run by a power supply unit.

Infrared sensors are a crucial part of designing a laser tag vest as not having perfectly functional sensors will ruin the whole project. These sensors will be run through intense testing and have many requirements to work inside our vest design. One requirement is to be able to sense one entire side meaning it can sense lasers from every direction but where it will be attached from or essentially any location the sensor is visible from. This will allow the sensor 5 directions of sensing for example this will allow the chest sensor facing forwards to be shot from the front, directly sideways from both the left and right side of the player, and directly above and below the player. Although it may change depending on the type of vest we buy our current vision is to have two sensors on the front on each side around the abdominal area to register hits to the main body, two sensors on the top of the shoulders to register hits to the upper body as well as from the side and back as they will be on top of the shoulder, and only one sensor dead center of the middle back to cover shots from behind. This sensor layout is optimal for us because it will register hits from all directions the front and back will pick up the main shots to the body and the shoulder sensors will allow the players to be hit from any direction as they will sit on top of the shoulders giving practically 360-degree sensing.

On the outside of the vest not only do we have the infrared sensors but we will have other really important parts that will enhance the user experience such as including LED strips and haptic feedback motors. The LED strips will cover the infrared sensors to show players where they are so they can aim for them as well as cover the perimeter of the vest to show the entirety of the player. These lights will be able to change color and will usually be the team color chosen at the start and will flash red when hit to signify that you are out. The haptic feedback motors are vibration motors that can have many uses such as vibrating when hit, shooting, or at the end of the game. This vibration adds a feel of realism to the vest design making it more realistic. These vibration motors will be placed near the sensors so that when a sensor is hit that motor will vibrate to show where the player was hit. These motors will run with the wiring of the sensors and LEDs throughout the inside of the vest so they are not noticeable and are more durable from being detached.

These wires from the infrared sensors, LEDs, and haptic feedback motors will be run through the vest and into a small smooth container where the rest of the components will be held including the printed circuit board, power supply, microcontroller, and wireless communication module. Inside this box, everything will be connected via the printed circuit board where all of the wiring from the external parts will come together with the internal parts to function seamlessly. The input and output running through the printed circuit board will be controlled by the microcontroller which will take in the inputs and use the embedded code to output the correct signals. These specific signals will be outputted using the wireless communication module to the main central computer system. The entire vest will be powered by one source this could consist of a rechargeable battery or a few AA batteries in series. This power source has many requirements and is crucial to function correctly or it could damage the other components in the system or even the users wearing the vest. The power source must output a minimum of 7 volts to power the entire system and meet the microcontroller's minimum voltage requirement. This power source will need to be able to match the gun's play length and provide sufficient power for the gun's systems for at least one hour of playtime.[24]

So now that we know how the phasor gun and vest work on a technical level how are we able to incorporate all of these features together into a working laser tag game? In each gun and vest, we plan to implement a system to connect the vest and gun to allow for seamless communication between the two. This connection will most likely be done via WIFI or Bluetooth technology which will allow our microcontrollers to be able to communicate with each other or more realistically all connect to a master control system. All of the microcontrollers will connect to a central computer system which will be able to communicate with each of them at the same time. Once we test to make sure each part can function on its own we can build the section of the gun or vest and once that section can function properly all together we can finally connect the microcontrollers and begin to implement more features. When all of the functionality of a basic laser tag system is finished we can begin to test our design and implement more software technology into the design of the gun and vest to add more game modes and some extra features to intensify the realism and make it more fun to play.

2.5 Product Research

Have you ever played laser tag whether it's at a specific place for laser tag or in the back room of an arcade you probably had fun but did you ever think to yourself why couldn't this technology be more advanced or easier to use? You may have thought why does the gun need to be connected via a thick wire or why does the vest feel like I'm getting ready to go scuba diving? In general, most laser tag places have a cheap laser tag system that’s not very user-friendly. We decided to try and fix some of the main issues involved with them and add our spin to it to make it more fun for the users. The first step to improving our system is to research similar products available on the market and see what they did to learn from their achievements and the mistakes they made. Next, once we have gone through other similar products we can focus on implementing the best features from each one and start to brainstorm ideas to add to our design. In general laser tag comes in all sorts of shapes and sizes and each one is different from the last doing some research will give us a general idea of what needs to be done and will give us more ideas of all the cool features we can add to make our design unique and stand out in a world of basic and boring laser tag systems.

Laser tag is a very modern idea with an almost endless amount of products available on the market. Not only have there been other products on the market but even multiple other projects have been made in senior design at UCF using a laser tag system. These projects will be helpful for us as we can use them for information on their process to learn from their mistakes and achievements. That being said, our project will not be a copy of an existing design and we will think of more ways to incorporate new ideas and designs into the game of laser tag. Including our design each laser tag system has some sort of contrast from the next and we need to be able to understand the differences in scale of our design vs other products to help focus the improvements that we intend to make.

When you first begin to research laser tag products you usually get two types of products although some fit between the two usually laser tag is either a cheap toy-looking model meant for kids to play with or an expensive and hyper-realistic model that is more suited for adults and is focused more on realism. That being said our product is going to fit into the realistic category as much as we possibly can so our research will be limited to practical models to help us learn more about what makes them so good. These models come from all sorts of websites and are for the most part extremely expensive most being between 1,000 to 2,000 USD. Although our design will be more advanced than the laser tag toys on the market these realistic models online have some features that we just don't have in the scope of a senior design project. Some features that other products have that will be more advanced than our system will be the gun model, the triggers, and overall system cohesiveness and usability.

It's very hard to compete with a large company that has multiple workers who are hired to specifically design laser tag systems and custom-made parts in a factory that has had years of testing done to it. With all these things said it's going to be obvious that our senior design product will be inferior in some components when compared to other online products. One feature we won't be able to implement to a degree of custom factory-made parts is cohesiveness and usability. With custom-made parts that are molded in a factory you know that what you are buying will have certain quality standards and durability. These parts are all designed to fit perfectly together making sure to leave no gaps in the gun sections and everything will fit together flawlessly. The trigger will move smoothly without getting stuck or having any major errors and the gun will be a perfect size and easy to hold and use. These examples of design constraints are just something that isn't realistic to mimic unless you are forgoing a major production line. This makes it hard to compete on a small-scale project when we are 3d printing everything ourselves for the first time with little experience. That being said it is imperative to know your strengths and weaknesses our plan when building a laser tag system was never to out-produce other similar products but to beat them in other aspects of the design such as having more user-friendly features and better game modes to play which in turn will make our design more fun for users to play.[3]

2.6 Similar Products

Knowing your competitors is super important in the world of business and when you are designing a new product you must always be aware of other products and their specifications. Some of the most important things to note when looking into similar products are their specific features and their exact component specifications. Specific features are really important to research and it is imperative to understand them and why they are implemented into the design. Exact component specifications are imperative to examine as you need to try to make sure your product can match those features. To get the most amount of information possible for our project we will be going over the most relevant laser tag designs such as the Military MILES, advanced laser tag products, cheaper laser tag toys, and even past UCF senior design projects.

2.6.1 MILES: Multiple Integrated Laser Engagement System, 1970/2010

The United States Military created the MILES in the 1970s an advanced laser tag system designed for military training. In 2010 a paper was released by the US Army Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) about the performance specifications for MILES. In this paper, they cover a lot of useful things about the MILES including safety features, specific specifications, and environmental changes. This paper goes into many specific environmental conditions and how they could affect the system for the main part they were all fairly simple but what I did find interesting was depending on the temperature the range of the weapons can differ by around five percent. Another very notable thing was the ranges themselves with the shortest guns being 550m and the longest being 1500m that distance is an extremely good standard being able to hit an enemy from almost a mile away. Overall one of the most interesting parts was the safety although it isn't like the specifications where they give you numbers they do talk about all types of safety measures that this system integrated into their design.

2.6.2 Laser War: Professional Laser Tag Equipment

Laser War is a professional laser tag equipment site that builds and sells anything related to laser tag. While researching different options to see which online laser tag equipment seller had the most advanced system this was the one that stood out. Laser War sells everything including up to seventy-five different types of guns ranging from pistols, SMGs, ARs, snipers, shotguns, and even rocket launchers. This website has high-tech laser tag technology which brings with it an amazing product and great specifications. Although each gun is different in terms of specifications they are all fairly similar in standards for the most part. One standard is battery life Laser war products have an amazing battery life with over twenty-four hours of playtime minimum for most guns. That combined with an amazing range of 100m on their pistols and up to 400m on their snipers are some great specifications for a laser tag system. [16]

In general, the products that they sell have very high-quality materials and great specifications to go along with them not only that but they have an amazing user interface as well. The user interface has many cool technologies and advancements including online statistics, remote controls, a mobile app, and personal game servers. These features that Laser War has are well designed and with their great specifications, they make a quality product. Although you may be thinking everything sounds great quality products come with a more expensive price tag. Laser war weapons can range from roughly three to seven hundred dollars per weapon and most good features you want with your weapon cost extra to add on. Overall a lot can be learned from Laser War and its products including setting a high bar for our design to attempt to match their specifications and overall business information in the world of laser tag.

2.6.3 Ammo Gear: Amazon Laser Tag Toys

When searching for a cheap product that will get the job done where better to look than Amazon. Amazon carries a great quantity of cheaper laser tag products from varying companies and prices can range from roughly fifty to two hundred dollars. These products are all fairly similar containing four guns usually pistols and four vests usually a single sensor and a band. These guns are designed to fully look like toys and are made that way to be sold to a younger audience of kids. These can come with some interesting features some of which are very similar to the more advanced systems such as teams, ammunition, health/player lives, vibration motors, LEDs, fire rate, and others. These features are pretty simple but important for the gameplay of laser tag. The specifications of these systems are where it gets interesting the range is 150 feet which seems small compared to the advanced systems. Although it seems small 150 feet is still pretty far and most laser tag games are not played at such far distances overall it can shoot fairly far away for its price tag.

Researching cheap toys is a great way for us to set a minimum standard in some areas of our design. This can help us gauge what is feasible to accomplish in our design. Although we may not have the minimum set for the specifications of our design to be as good as the toys in every aspect we will strive to at least match them. This means that our design should be able to accomplish everything that a cheap laser tag toy can do and much more.

2.6.4 Let's Have a Blast: UCF Senior Design Project

Researching a former UCF senior design project is extremely helpful as we can learn so much from what they accomplished and the struggles they had. However, since we can't see what the final design looked like or the specific specifications they managed to accomplish in their project it helps us set a standard for what we should achieve at minimum. Some specifications they had are fairly similar to ours with 1-hour battery life, 20 feet range, 95 % accuracy, and 2 game modes. However, after looking at their design and comparing it to what we plan to accomplish I believe that we will be able to beat them in almost every aspect. That may sound like a bold claim but this is mainly because of how we plan to focus our project more to enhance those specifications.[19]

Firstly one reason I believe that our design will be able to beat the range and accuracy of their device is because of our gun design and size comparison. They decided to make their gun a small pistol and tightly fit all the components inside which has its advantages in its portability and minimal size but this however will see a sacrifice in their specifications. Our design however is going to fit inside a larger gun which will take away from the portability of a smaller gun but in return will give us more room to improve our specifications. Having this room in our design will give us the freedom to adjust the gun lens and beam width to make our infrared beam stronger and have more range and accuracy. Overall this will give our design the edge in the specifications of range, accuracy, and overall emitter efficiency.

Another specification that we should be able to beat is game modes and gameplay. In their design, they focused in my opinion too much on the user interface of the gun itself giving it buttons to control game modes and overall all these features that could just be controlled from the computer they all connect to. They also went through the effort of designing an app to access and control the gameplay when we find it easier to just save the time and effort of doing that and make all those features controllable by the master control computer. All this time that we can save by not adding these features will be put into designing game modes and improving the gameplay.

Some other notable features that they included were an accelerometer and gyro these features are used so that when the gun is pointed downwards it reloads. Our design however will have a magazine that will be able to be attached and detached from the gun and sense that to reload the weapon. They also included in their design a speaker to make sounds when firing and hit which we will not be including because it feels unnecessary for our objectives and goals. Another feature they included was a buzzer which seems like it is completely unnecessary and would get annoying at times.

Overall this project was extremely well-designed and was a good read into what we need to think about for our project. While reading their project paper we saw some really interesting and specific things we had not considered in our design so learning about them will greatly help us. Their design was completely different focusing mainly on the portability of the gun by making it a small minimalistic design and having a fully functional user interface in the gun and with a mobile app. Our design however will be a larger upgraded version of this design including some of their features but in a bigger model to increase specific specifications. Taking that into account they did an amazing job with their project and we hope that our project can build on what they have accomplished.

2.7 Design Variations

Now that we have given you some examples of laser tag products you may be wondering are you just making a copy of already existing products and designs? No, we are not we intend to implement features of our own into our design and see how far we can advance the game of laser tag. These features we intend to implement all stem from improving the game of laser tag by making the gameplay more fun to play and user-friendly. When we decided to make a laser tag game we liked the idea because of its extendability if we come to realize that building a laser tag system is more advanced than we anticipated we will not be able to add all of the features we intend to. However, the opposite is also true if we can build a functional laser tag system with ease we will try our best to implement all our features and possibly even add more as we go along. Overall these design variations are more just general ideas that we hope to implement as many as we can into our project to improve it.

2.7.1 Fire Rate

Fire Rate is extremely important in any sort of gun game including laser tag. The fire rate modes will include single fire, semi-auto, full-auto, and burst mode. These will change how the gun is shot and affect how the player plays the game. Most laser tag games are played with single fire but having the option to change can add some more variety to the game. Single fire will shoot a shot every time the player presses on the trigger and will only shoot another once the trigger is released and pressed again. Semi and full auto are very similar and will be activated whenever the trigger is held down until it's released the difference between the two is how fast it fires bullets. Burst mode like auto will be activated when held down but will shoot a quick fire of three shots then pause then shoot three more this will go on until you release the trigger. These features can be inputted by a knob on the gun or on the computer before the game and are fairly easy to implement using code. Having these features can make the game more interesting but watch out the more bullets you fire the more you will need to reload.

2.7.2 Reload

Any advanced gun system isn't complete without a functioning reload system or else you can just shoot forever making the game less challenging and fun. In our design, we plan to implement this reload system into our 3D gun design by giving our gun a physical button to hold down which will release the magazine allowing players to pull it out and reload it. This will be completed with a sensor that will detect if the gun magazine has been pulled out and when it's placed back in. Connecting the input to some code on the microcontroller is fairly easy and will give our gun a fully functioning reload system. The hard part of this implementation is making sure the 3D-printed gun dimensions and buttons are perfect and allow for a clean fit of the magazine and a smooth reloading process.

2.7.3 Difficulty Levels

Difficulty levels can greatly change the user experience of laser tag depending on who's playing it. Let's assume you let some kids play with the laser tag system if you make the width of the laser really small they will never be able to aim perfectly at the vest's exact sensors to be able to register a hit and they will have no fun playing the game. However, if you make the beam really wide they will have way more fun and register more hits on their friends. Now if we give the laser tag system to a group of weapon-trained adults and leave the width wide every shot they take will be a hit and nobody will be having fun playing. This feature will allow you to change the difficulty level of how hard it is to shoot someone to make the game more user-friendly for all types of ages and skill gaps.

In our design, we plan to implement a difficulty mode which will make it easier or harder to aim the weapon depending on which mode you choose to shoot a target. To implement this concept we plan to change the size of the beam coming out of the gun bigger being the easy mode making it more likely to register hits and smaller being the harder mode which will register fewer hits. Implementing this feature could be done in multiple ways which is going to be extremely hard and will require lots of testing. One way we could implement this is by using a motor to move our infrared emitter closer or further away from the lens which could focus and unfocus the light to make the beam width smaller or larger. Another way we could do this would be inside the barrel to have a mechanism that will tighten or loosen the hole that the light comes out of to change the size of the beam.

These options could have different effects on the laser tag system as a whole including range and accuracy which we need to take into account to see which option is better or easier to implement. These options could both theoretically work but since we have no experience in optics and this isn't a feature that is common in most laser tag systems we expect it to be difficult to implement. However, we believe with lots of testing on different lenses, distances, and hole sizes we will be able to change the size of the infrared beam and add this feature to our project. Having multiple difficulty levels can be extremely important in a laser tag system as not every person plays the game the same and can change the user experience.

Shotgun mode builds slightly upon the difficulty level feature but with some more added things. First off the beam width will be increased quite a lot which will give the player using the shotgun a wider range to shoot and hit a target. However, this comes with some setbacks shotguns will have a range and damage feature so when you shoot your opponent from a far range it won't do much damage. The shotgun mode also will hold less ammo, and if we can implement it without worsening other features even add a pumping action between shots. We can also use these features to try to implement different types of weapons with all sorts of cool features. This will give the users more options to choose from when deciding what gun they want to bring with them onto the battlefield.

Implementing these features is easier said than done and we will need multiple things to work to be able to add this feature into our game. First off we will need the difficulty feature that will change the width of the beam to function properly to mimic a shotgun's wider hit area. We will also need our infrared sensors to be able to read different light amounts to be able to see roughly how far away the shot was and adjust the damage done accordingly. These are not simple to implement and we will only know if it will work once we start testing. However, we believe that although it may be difficult it's still possible and we will try to implement this to add another cool feature to make the game more enjoyable.

This concept of adding accessories to make some minimal user-friendly features is fairly simple and relatively easy to implement but we have to weigh which are worth the effort and price to add. Red Dot Sights would be a cool feature to add to our gun which would implement a screen on a sight to display things including a red dot where the gun is aimed to help the player aim at the opponents. A simpler version would be a sight without the fancy holographic to save money and time on things that are more important in our project. Other accessories that could be added could be grips, lasers, flashlights, and some others.

2.8 Objectives and Goals

The main objective and goal for this project is to engineer a working laser tag system that can replicate the dynamic experience of playing laser tag. By utilizing modern infrared and sensor technology, we will be able to accurately detect “hits” between the user and record the data. Some small goals and objectives are listed below.

Overall Final Objectives

- Build a working laser tag gun that emits infrared lasers.
- Build a working vest that can detect infrared lasers.

These overall final objectives are overarching goals that we need to achieve to complete the project. These goals can further be simplified as listed below.

Laser Gun Objectives

- Utilize an LCD display to show information about the game and gun.
- Emit infrared lasers to shoot at other users.
- Be able to properly reload and reset the amount of bullets in your gun

Vest Objectives

- Utilize sensors to detect whether you were “shot”.
- Give feedback to throw vibration motors to tell if you were “shot”.
- Record data and show where you were “shot”.

Stretch Objectives
- Transmit the data to a computer to report on fatal shots or unfatal shots
- Replicate a recoil system for the laser guns
- Connect through wifi or Bluetooth.

2.9 Required Specifications

This project requires many specific specifications in order to fully function together properly. Making requirements on these specifications can help us set minimum goals for what each component must achieve.

Table 1. Table of Specifications

Specifications		
Vest Response Time	The response time from the sensor receiving the infrared light to the system outputting that it registered will be less than **1 second.**	**≥ 1 second**
Trigger Response Time	The response time from the press of the trigger to the activation of the infrared laser will be less than **1 second.**	**≥ 1 second**
Infrared Receiver Accuracy	The system will be able to accurately detect at least **80%** of the hits that are aimed properly at the receiver	**≤ 80%**
Battery Life	The battery will allow at least **1 hour** of playtime	**≤ 1 hour**
Areas of Receivers	The laser tag system will consist of at least **3 areas of hits** per vest unit	**≤ 3 areas of hits**
Battery Voltage	The battery will be able to output a minimum of **7 volts**	**≤ 7 volts**
Infrared Lights	The infrared lights are expected to emit light at a **wavelength of 940 nm**	**940 nm**
Motors	The motors will be able to spin at a rate of **16000 RPM** at **3 volts**	**≤ 16000 RPM** **≤ 3 volts**

2.9.1 Hardware Specifications

- A Microcontroller Unit (MCU) and a designed PCB are required for the laser gun and vest.
- RGB LED with an RGB Controller will also be added to the laser gun and vest.
- Both the vest and laser gun will have a WIFI/Bluetooth module in the PCB with an antenna to receive the signal.
- The vest will be equipped with an Infrared receiver so that it can be able to detect when the laser gun has hit it.
- In addition, the vest will have a Servo Motor Controller to operate the vibration motors; this will be useful in alerting the user when they have been hit.
- Both the gun and vest will utilize a battery as well as a voltage amp that will make up the Power Supply Unit (PSU). The battery life of each system is estimated to be 2 hours.
- The laser gun will be equipped with an LCD display to show the user data
- A trigger button, recoil buzzer, and reload button will also be equipped onto the laser gun.
- Wifi/Bluetooth module to allow seamless communication between components

2.9.2 Bluetooth Specifications

- Bluetooth version: 2.0 + EDR (Enhanced Data Rate)
- Frequency: 2.4 GHz ISM band
- Modulation: GFSK (Gaussian Frequency Shift Keying)
- Transmit power: Class 2 (up to 4 dBm)
- Sensitivity: -80 dBm typical
- Range: approximately 10 meters (or 33 feet) in open air
- Profiles supported: SPP (Serial Port Profile), HID (Human Interface Device) and others
- Operating voltage: 3.3V to 5V DC
- Operating current: less than 50mA
- Standby current: less than 2.5mA
- Sleep current: less than 1mA
- Interface: UART (Universal Asynchronous Receiver/Transmitter)
- Baud rates: 1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200, 230400, and 460800
- Operating temperature: -20°C to 75°C (-4°F to 167°F)

2.9.3 LEDs Specifications

- Superior weather resistance
- 5mm Round Standard Directivity
- UV Resistant Eproxy
- Forward Current (IF): 30mA
- Forward Voltage (VF): 1.8V to 2.4V
- Reverse Voltage: 5V
- Operating Temperature: -30℃ to +85℃
- Storage Temperature: -40℃ to +100℃
- Luminous Intensity: 20mcd

2.9.4 Hardware Flow

The overall system for this laser gun project will consist of the basic necessary components such as an infrared emitter, infrared receiver, microcontroller unit, and LCD screen. But it will also consist of other components such as buttons, RGB LEDs, buzzers for gun haptic feedback, motors for vest haptic feedback, and a wifi/Bluetooth module. These components will help enhance the gameplay of the laser gun game and also provide haptic feedback to the user to enhance the realism of the game. Each component can be further researched and explained thoroughly about its purpose in the project through this document. The figure below shows a flowchart on how each component will interact with each other and the work distribution between each of the members of this group.

The hardware flowchart can be easily explained by splitting it into two major parts of the project and different major components in each part. The two major parts of the project consist of the laser gun and the laser gun vest that each player will have and utilize to play. Both of them will communicate with each other to allow the user to better understand the situation or what is currently happening in the game. The wifi/Bluetooth module will assist in allowing communication between the vest and the gun and will allow the separate entity to become one complete system instead of two different entities operating by themself.

The laser gun hardware's flow can be better understood by examining the different expected outcomes due to specific actions across its components. Such components consist of the trigger system, central PCB, power supply, and IR emitters. The trigger system is very pivotal due to its important role in initiating the laser gun's firing mechanism. Which upon activation will send a signal to the IR emitter to emit a laser beam for detection by the target's vest. This will be achieved by adding a button to sense the trigger mechanism and send a signal to the MCU to activate the firing sequence. Also to enhance the user experience and simulate a more realistic firing mechanism, the gun will contain a feedback mechanism such as a buzzer where its goal is to simulate or mimic the recoil and tactile feel associated with a real firearm. Additionally, the LCD display and RGB will further enhance the gameplay experience by visually enhancing the gameplay and the LCD display screen adding and providing critical game-related information therefore keeping the user informed of their current status and the status of the game. And finally, the integration of the Wifi/Bluetooth module will allow seamless communication between the gun and the vest ensuring an interactive experience with our product. This connection between the gun and vest will be crucial to allow the experience to feel smooth and ensure no lost information when using the product.

The vest hardware's functionality is very similar to the laser gun hardware, with various connected components that will allow and ensure a smooth and integrated experience when using the product. The key components in the vest hardware flowchart include the power supply, Wifi/Bluetooth module, infrared receivers, RGB LEDs, and haptic feedback mechanisms. The main component in the vest is the infrared receiver as they are critical in detecting when the user is "hit" by the laser emitted from the laser gun. Upon receiving a signal by the emitter the sensors on the vest will relay the information to the MCU in which the MCU will process the data to determine the status of the game and the user and whether the game will continue. In addition to the calculation of the status of the game, the haptic feedback mechanism will also generate tactile feedback simulating the experience of getting shot. Also, the RGB LEDs on the vest will provide a visual cue to being shot to not only the user but also to other users around you therefore enhancing the immersive aspect of the game. Furthermore, like the laser gun hardware flow chart, the vest will also contain a Wifi/Bluetooth module to facilitate communication between the vest and the laser gun. This addition will be crucial in allowing the vest and guns to register hits and ensure a smooth connection and experience when using the product. The combination of all these components will help deliver a seamless experience and aims to create an engaging experience for the user.

Figure 1. Laser Gun Hardware Block Diagram

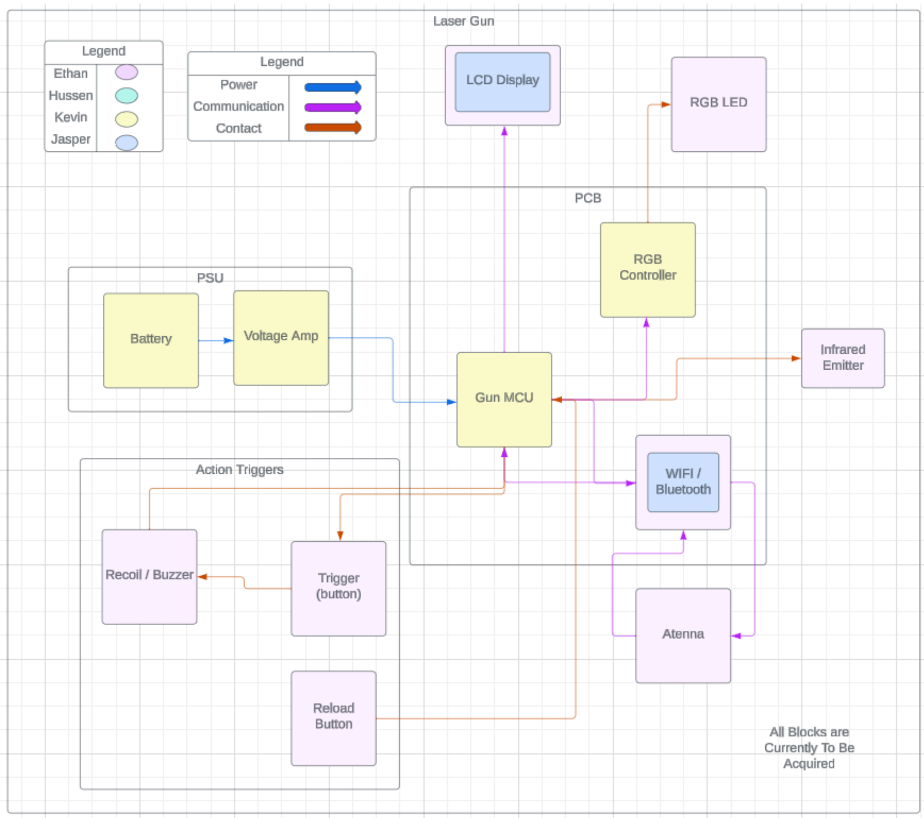
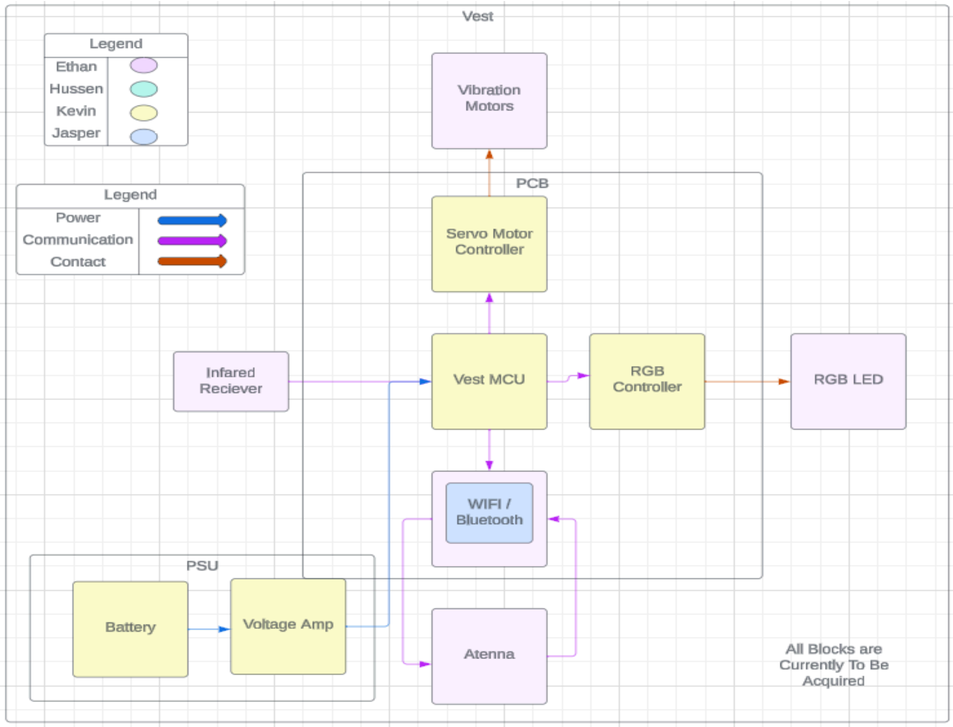


Figure 2. Vest Hardware Flowchart



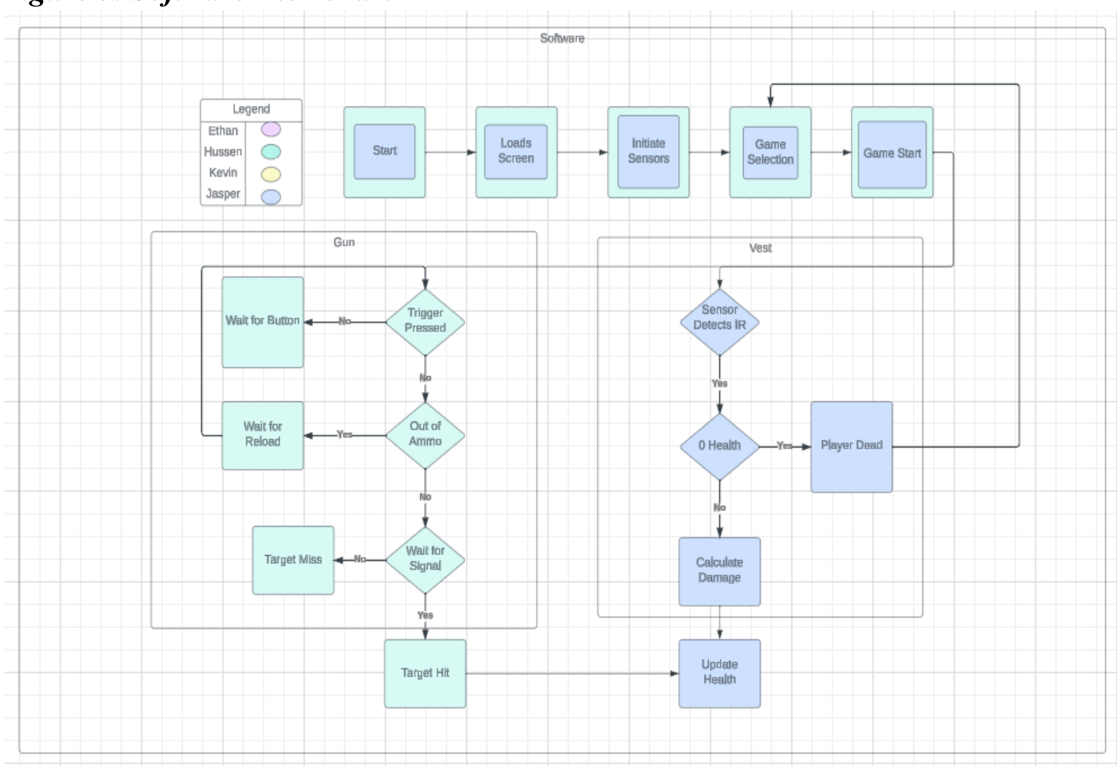
2.9.5 Software Specifications

- The software will be able to start or power up the system.
- The software will be written with different game modes which will control individual elements of the game.
- Be able to access and control the inputs and outputs from the main hardware devices.
- Hold information like a player's ammo, health, team, and much more.
- The software will be able to run tests on each individual device to make sure it's functioning correctly.
- Have functioning delays and timers for integrating the inputs to be able to control the output's timing correctly.
- Interrupts or checks for when the inputs detect and are able to sufficiently output the results.
- Be able to receive information from multiple sensors and process their information

2.9.6 Software Flow

For our laser gun design project, there will be a software program running in the background that will decide the status of the game and also relay any information about the game and the player’s situation at the time. We will use a microcontroller to communicate between the different hardware components and relay the information gathered by the components to the program. The figure below will show how the software will process and receive all outside information and how to proceed based on the gathered information. The flow can be described starting with the game, where all starting information will be loaded onto the screen on the player's gun. Afterward, it will initiate all outside components such as sensors, emitters, or motors needed for the game. In which the game selection screen will be then loaded onto the LCD screen in which the player or players will decide what game they will play. At this point of the software it will be split into two different running codes in which one will be the laser gun itself and the other will be the vest that the players will be wearing. The software for the gun will start with the basic waiting for a trigger press in which it will check if the magazine of the gun is not empty and then proceed to shoot using the infrared light emitter. The IR laser will then activate the sensors on the vest if the player is hit by the light. Based on the hit it will calculate the health of the player and if the player still has enough health to continue playing the game. If the player health reaches zero then the game will end and the player will have the option to restart and play again.

Figure 3. Software Flowchart



2.10 House of Quality Analysis

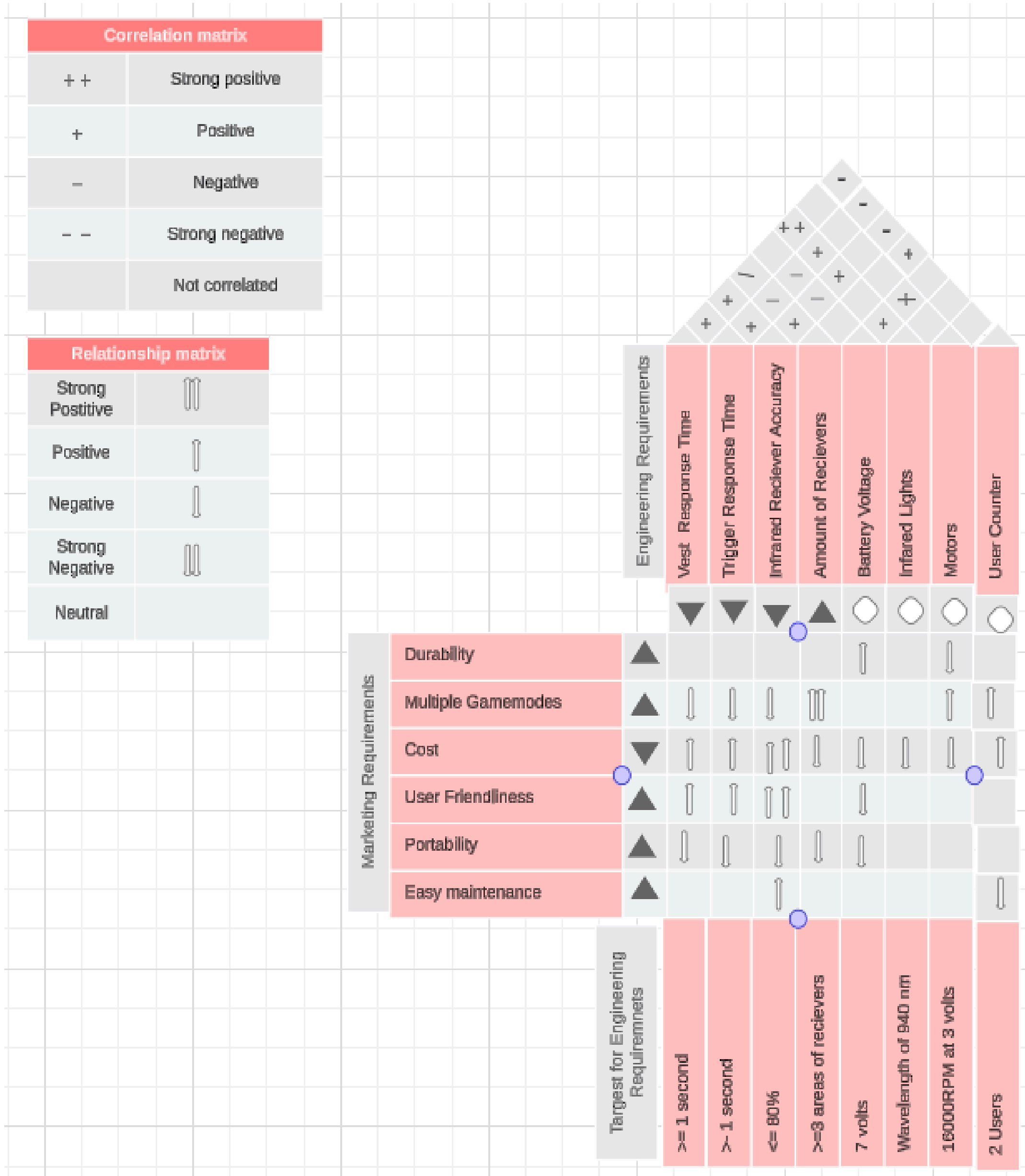
This House of Quality diagram is a chart that represents the engineering requirements, marketing requirements, and their relations with each other. This diagram assists us in analyzing the comparisons between the different requirements and specifications required for our project. And also connects and describes their relations with each other through the varying degrees of ranking such as strongly negative, negative, positive, and strongly positive correlation. Each of these varying degrees of correlation connects two requirements and represents how they influence each other when analyzing all the engineering and marketing requirements and also all the different specifications. Also excluding its usefulness in showing correlations between different requirements and specifications it also shows the different priorities that each requirement contains. As we further research the steps and requirements for our project we need to understand which requirements take priority in importance as compared to others. And the amount of sacrifice we can make to improve another requirement that contains a higher priority as compared to other requirements. The direction of the polarity also matters as it shows whether a higher number or a lower number means better improvement when researching the requirement.

Marketing requirements are important requirements that would be required to be considered when trying to place the product onto the open market. As such one example of a marketing requirement is the overall total cost of the product. The cost is a major component of a marketing requirement because if the overall cost is not appealing to the regular consumer then the product will easily fail and not be successful when placed in the market. Another marketing requirement could be durability, user-friendliness, and easy maintenance. Each one of the marketing requirements places the bottom line requirement to be successful when placed in the open consumer market. By developing and establishing each requirement in the beginning then we will be able to establish clear long-term goals and short-term goals when proceeding with the project. Also when researching what parts we will utilize for the project we will compare them with the marketing requirement to make sure that the components purchased for the project will be able to accomplish the requirements needed.

Engineering requirements represent the different engineering specifications and goals that we have established for the project. For instance, sensor distance is one of the engineering requirements that we decided to focus on since the laser distance would allow ease of use and also be easily demonstrable while doing a demo. Each one of the requirements or specifications mostly focuses on hardware or software components of the project and certain aspects that can be seen when using the product. This is still vital to the project to establish a starting point and a bare minimum that we will try to accomplish when working on the project. Some of these engineering requirements can also be compared to other similar projects or products that can be found in the market. Therefore we can set a bare requirement that can properly set goals to achieve so that our product can be better than others in the market. This is largely important when companies review possible products that they will research and develop. Especially when they are competing against other companies that are making similar products as the one they are developing. Also, we will compare the engineering requirements to the components we will be researching to ensure that the components researched will be able to accomplish the engineering requirements and also be able to compare components to decide which one is a better fit for the project by utilizing the House of Quality diagram to show which requirement should be prioritized when researching for components.

In conclusion, the House of Quality helps establish marketing and engineering requirements that should be used to strive and accomplish when making the project. This is important for companies to consider when making their projects due to the importance of being successful when placed in the market. Also when working on our project we will analyze the House of Quality to ensure that we accomplish all the requirements we establish when researching and starting the project.

Figure 4. House of Quality



2.11 House of Quality Breakdown

The House of Quality is meant to establish proper requirements for the project. For each project, they all need particular requirements unique to their own situations that will be reflected in the market and different engineering specifications. Overall these requirements will establish a basic starting point and goals that we need to achieve when researching and developing our project. Of course, since these are just bare minimum requirements, the overall goal should be trying to strive higher than the bare minimum established in the house of quality. Therefore, the House of Quality will establish a very solid foundational goal for our project but it is in our best interest to improve to achieve a better product than other products similar to our own.

2.11.1 Engineering Requirements

As seen before, engineering requirements establish the basic hardware and software expectations for our project. These requirements highlight the goals that we established for our laser gun project and define specific targets with numerical goals that would ensure the success of our project. For our project, these engineering requirements were necessary to establish certain specifications to achieve when we demo the final product for our laser gun project.[8]

1. **Vest Response Time:** The vest response time is very important to make sure that the constant flow of the product is ensured. The time between the sensor receiving infrared light and the haptic feedback motor or the MCU receiving the input from the sensor is vital to keeping immersion realistic. Also if there was a delayed response time then the user could possibly be in the game longer than we wanted due to the delayed response time. Establishing a goal to achieve for the response time will ensure that the immersion and experience will be upheld when creating the project.

2. **Trigger Response Time:** Ensuring that the trigger response time to the infrared emitter is short would help achieve a more enjoyable user experience. Shortening the response time would allow the user to feel more involved and prevent any issues where the laser gun feels unreliable and not precise when playing. Also, the response time for the button on the trigger should be kept short to prevent any delay issue or caching issues when considering commands sent to the MCU and the MCU sending commands to the infrared emitter.

3. **Start-Up Time:** Establishing a start-up time goal, will ensure that the user will not have to unnecessarily wait for the whole system to boot up. If the start-up time for all the sensors emitter and other components in the project takes too long then the user will have a poor experience. This will also make the whole product seem professional as there isn't a weird stop in the flow of using the product.

4. **Amount of Receivers:** The number of infrared receivers would help assist and ensure precision and reliability when checking if the infrared emitter successfully hits the user. By increasing the amount of receivers you can ensure that the reliability is high. But at the same time if you increase the amount of receivers it would also increase the price of the overall project.

5. **Battery Voltage:** Many of the components on the project need to be battery ran. So by ensuring that the basic amount of voltage is achieved by the battery then we can ensure that the battery would provide enough voltage for all the components used. Also when comparing compatibility with the components to the system we can ensure that there is enough voltage to utilize the component.

6. **Infrared Light:** Infrared light is a major component of the engineering requirement for this project. It is important that all the light used for the project contains the same wavelength to establish a proper connection from the emitter to the receiver. Also is very important if we code bits into the infrared light to send information through the laser beam.

7. **Motors:** It is important to establish a required speed for the motors used for possible haptic feedback on the vest. If the motors are unable to spin fast enough to cause a vibration due to an offset weight then the user will not be able to feel the haptic feedback whenever the receiver senses the emitter infrared light. Therefore lowering the user’s experience when using the product.

8. **User Count:** Since the laser tag system is made for multiple users it is very important to establish a bare minimum amount of players needed to use the product. This would largely increase the marketing expectations and also increase the user experience when using the product.

2.11.2 Marketing Requirements
Similar to engineering requirements, marketing requirements help define and establish what consumers and the possible market desires from our project. This helps create requirements and specifications that we need to accomplish to be able to apply our product to the market and become successful. Some examples of requirements include cost, durability, and portability. For this project, these marketing requirements are necessary to establish a good foundation for a good product to present for our laser gun project.

1. **Durability:** The durability of the overall product is a very important requirement that we need to consider when researching and developing our project. With the expectation that our project will be used outdoors and in very intense and rough situations, the durability of the product will determine the user's experience. It is expected to be able to handle low to medium impacts and also function in varying different environments and conditions. If the product isn’t durable enough then the user's experience would be largely affected since as a result, you would have a faulty product that can’t be used in the expected situation. This would largely affect its capability to succeed in the open market therefore making it a very important marketing requirement when discussing, researching, and developing this project.

2. **Multiple Game Modes:** For this project, we decided that the bare minimum amount of game modes for our project would be at least 2. This would allow the user to experience multiple different ways to play and utilize our product. Also making the marketing of the product more appealing to consumers. As such having multiple game modes is an important marketing requirement since it can make our product more appealing as compared to other products in the market where there is simply just one way to use the product.

3. **Cost:** Similar to durability, cost is a very important marketing requirement for the overall product and something that we need to consider when researching and developing our product. This not only affects the users that use our product but also our members developing the product. This also affects the research of components necessary for the project as the cost-effectiveness of certain components would be considered when compared to other components. Also by having the overall cost of the project lower than other competing products in the market, it would increase the appeal to the consumers if and when the product is released to the consumer market. As a result, the cost is a major aspect of marketing requirements that need to be considered when working on this project.

4. **User Friendliness:** Ease of use is an important marketing requirement that needs to be considered when producing and developing the product. Having a product that is confusing to use makes a lesser appeal for the product when placed in the consumer's market. Making the overall system easier to use for any new user allows it to succeed when released into the market making it a marketing requirement that we need to include in our house of quality. Understanding the importance of making our product easy to use helps assist in improving our product and making it the best we can as compared to other similar products in the open market.

5. **Portability:** Portability plays a similar role to user-friendliness in ensuring that the user has a good experience while using our product. The portability ensures that all users will be able to use it in an efficient and enjoyable way. A product design that is too heavy or too small will affect the overall experience of the product. Also, this marketing requirement will also affect the overall design of the product due to every single component of the project will affect the portability of this project. Hence this is an important requirement that needs to be considered when researching and developing components of this project.

6. **Ease of Maintenance:** The ability to maintain and clean the product is an important factor that many other products ignore as an important aspect of their product. This one factor is affected by many other marketing requirements such as portability, user-friendliness, and durability but at the same time is still an important factor by itself. If the product experiences any bugs or issues when the consumer uses the product then it should be able to quickly reset itself or solve the obstacle that it experiences by itself. There are many products in the real world that fail at this aspect requiring the user to contact assistance from the company. This experience can lower the overall expectation and demand of the product in the real-world market.

3.0 Research and Investigation

Research and Investigation play a pivotal role in large-scale projects such as this. It is particularly important when evaluating technology decisions. We must compare and contrast the pros and cons of the tools we plan on using to aid our project. In doing so we must make informed decision making, risk mitigation, and optimized performance.

Research allows our team to make informed decisions. When comparing technologies, thorough investigation helps identify the most suitable tools, frameworks, or languages. By understanding the pros and cons of each option we can choose the right tools that align with our project goals, scalability, security, and requirements. Large-scale projects such as this often time involve significant dedicated investment of time, resources, and money. Research helps mitigate these risks by discovering new, cheaper, and more efficient options. Researching our software technologies will provide insight into their community support, stability, and long-term support. By taking into account the risk in each choice, we are able to make strategic decisions that minimize impacts. Research allows us to evaluate performance and real-world use cases. Investigating software technologies will help determine their responsiveness, efficiency, and portability. Selecting well-performing tools will allow us to develop quicker, troubleshoot efficiently, and give us the option to optimize the system in general.

3.1 Technology Comparison

Comparison is a great way to evaluate the differences and weigh the advantages and the disadvantages. Therefore, before development and prototyping having a well-thought-out overview of what works and what doesn't.

1. **Technology Evaluations:** Technology evaluation for software research can help us the right programming languages, libraries, and frameworks for our laser tag system. We need to consider factors such as real-time communication, power efficiency, and ease of development. Investigating existing laser tag software solutions or related fields can provide valuable insights. Comparing different MCUs (such as Arduino, MSP32, and Raspberry Pi) is crucial. Each MCU has varying capabilities, power requirements, and I/O options. In addition the performance of the emitter and receiver LEDs and their sensors compatibility with the MCU.
2. **Interoperability and Integration:** Research ensures that the selected software and hardware components work seamlessly together. Investigate communication protocols (like Bluetooth, Wifi, or RF protocols) to enable wireless connectivity between the laser tag guns, vests, and central control unit. Investigate how the emitter LEDs interact with the receiver LEDs. Are there any synchronization challenges? How do we handle collisions during gameplay?
3. **Power Management and Efficiency:** Research battery technologies and power-saving techniques for MCUs and LEDs. Investigate sleep modes, duty cycles, and low-power states to extend battery life during gameplay. Explore sensor power requirements. For instance, ultrasonic sensors may consume more power than infrared sensors.

4. **Safety and Regulations:** Investigate safety guidelines for laser devices. Ensure that the emitter LEDs comply with laser safety standards. Research local regulations regarding wireless communication frequencies and power levels.

3.1.1 Software Technology

The Arduino IDE is a crucial tool for writing, compiling, and uploading code to Arduino and supporting boards. Arduino has many different features making it stand out from the rest. With a responsive interface, auto-completion, and a debugger, it creates a compelling case. In addition, its compatibility is one of the reasons why the Arduino IDE and its libraries make portability and support. The primary language is C/C++, although they can be programmed using Assembly language. For the duration of the development, we plan on using C/C++. Communication with MCUs uses a variety of protocols.

The ESP32 chip is compatible with Arduino IDE. The Arduino-ESP32 support can be installed from the IDE. The ESP32, like other Arduino-supported microcontrollers, benefits from libraries and standardization of base Arduino functions. Using the Arduino IDE is familiar for programming the ESP32, although more complex projects may require additional tools.

1. **Universal Asynchronous Receiver-Transmitter (UART):** Widely used for serial communication, it uses two wires (TX and RX) to transmit and receive data sequentially

2. **Serial Peripheral Interface (SPI):** A synchronous communication protocol for connecting multiple devices to a single master.

3. **Inter-Integrated Circuit (I2C):** A multi-master, multi-slave protocol for communication between devices like sensors and displays.

Additionally, one of the most popular IDEs, Visual Studio Code is well known for its wide range of extensions. As such, there exists an Arduino extension in the Visual Studio Code environment that allows the user to program Arduino supported boards and such. We must select the board programmer and the board type, then we must select the serial port and choose the USB where the board is connected. Additional packages can be installed. VS code has many advantages such as IntelliSense, debugging, and git integration. It has a wide array of extensions that make for a coding experience better.

Table 2. Different IDEs

Aspect	**Visual Studio Code**	**Arduino IDE**
User Interface	Lightweight, customizable, and extensible. Supports themes, extensions, and plugins.	Simple interface with limited customization. Basic layout with minimal visual options.
Code Editing Features	IntelliSense for autocompletion. Debugging capabilities	Basic code editor with syntax highlighting Limited debugging tools
Language Support	Supports multiple languages (C/C++, Python) and more.	Primarily focused on C/C++
Extensions and Plugins	A vast library of extensions for various tasks. PlatformIO integration for embedded dev.	Limited extension support. No built-in support for other platforms.
Project Management	Integrated task runner and build tools Git integration	Simple project structure
Community and Support	Active community, forums, and online resources	Established Arduino community
Platform Independence	Available on Windows, macOS, and Linux	Platform-specific (Windows, macOS, Linux)
Library Management	Comprehensive tools for library management	Basic library manager

Both tools have their strengths, but VSCode with PlatformIO provides a more powerful and feature-rich environment for MCU development. It offers better language support, debugging capabilities, and a wide range of extensions

3.1.2 Hardware Technology

Virtually every electronic device utilizes a voltage regulator, from large industrial machines to everyday consumer products. What a voltage regulator does is it takes in an input voltage and creates a constant output voltage, even with any changes in the load condition coming into the regulator. This helps protect any electrical components that require a steady input at a specific voltage level such as an MCU in our case. Another common use of a voltage regulator is to extend battery life; we will use this feature in our system too. By making sure that we operate within optimal conditions, and we reduce how much unnecessary power we are consuming we can greatly improve the battery life of our system. Now that we have talked about the use of a voltage regulator let’s talk about some of its most important characteristics: output voltage stability, dropout voltage, efficiency, etc.

Dropout voltage is particularly crucial for voltage regulators as it is the minimum difference in the input and output voltage to maintain stability with the output voltage. Dropout voltage is particularly important for linear regulators. The reason for this is that the way this device regulates the output voltage is by dissipating the electrical energy; therefore, the dropout voltage itself defines what the efficiency of a linear regulator will look like. Let's talk about some of the implications of dropout voltage starting with efficiency and battery life. When we are using a battery-powered device, as we consume more of the energy in the battery, we know that the input voltage can decrease. Thus, if our dropout voltage is too high then the voltage regulator will not function properly anymore and not utilize the full capacity of the battery. Due to the way linear regulators use heat dissipation a larger dropout voltage would result in more heat generated. Even for systems with constantly fluctuating input voltage, if the dropout voltage was too high then when the input voltage gets closer to the output voltage, we would experience system instability. It is for these reasons that the use of a Low-Dropout (LDO) Regulator is one that is highly recommended. This type of linear regulator is designed to be efficient and often has a dropout voltage of less than 0.3 volts. LDO Regulators also allow for much more flexibility in a system with choosing the power source.

As we already know there are different types of voltage regulators with their own advantages for each situation. We are going to be looking at and comparing two different voltage regulators: linear voltage regulators and switching regulators. First, let's look at the operation principle for both regulators starting with linear, using a voltage-dividing device controlled by a feedback system a constant voltage is obtained; any excess voltage is dissipated. The way a switching regulator operates is much more complex and involves an inductor, diode, and switch. How it uses the electrical components is by converting the input voltage to an AC signal and using an inductor and capacitor to store the energy to then rectify the output and produce a DC voltage that is stable. Comparing the efficiency of the two regulators it is very clear that linear regulators are much less efficient, and even more so when there is a large difference in the value of the input voltage and the output voltage. The reason for this is that efficiency is simply the ratio of the output voltage to the input voltage so the larger the difference the lower the efficiency. Switching regulators are usually in the range of 80% to 90% more efficient since they waste significantly less amount of power. This is achieved through control systems that manage energy flow to waste less power. For our senior design project, one of if not the most important aspects to consider is the cost and complexity of any device or technology we implement in our system and the voltage regulator is no different. The linear regulator is by far a cheaper design and much simpler to implement, mainly because it requires fewer components. On the other hand, switching regulators have a much more complex implementation with a more sophisticated circuit design and more components such as inductors, diodes, capacitors, etc. Also, switching regulators have complex control circuits to manage switching, all of which contribute to a more difficult and more expensive system. When it comes to the noise interference of both regulators, the linear regulator provides a much cleaner output which makes it the best option in cases where noise-sensitive devices are being used. Due to the switching mechanism in the switching regulator, there is more electrical noise and ripple; this could result in the need for a more complex design process to help mitigate Electromagnetic Interference (EMI) through shielding, filtering, etc. In situations with a high-power load, it is necessary that a heat sink is utilized to manage the heat produced from linear regulators, this can in turn lead to more physical space needed in a system and an increase in cost. A switching regulator generally does not produce nearly as much thermal activity when compared to the power load and therefore is regarded as a much better fit for high-power applications.

After carefully considering both options for the voltage regulator, the linear regulator with a low dropout voltage has better performance in the sections that we find the most paramount. For example, simplicity, cost, noise sensitivity, and efficiency are the main advantages of the linear regulator and are exactly what we are interested in the most.[1]

To create a battery-level measurement system, we need to design hardware that allows us to get an accurate reading of the voltage level. Firstly, we should have a simple voltage divider to lower the voltage level of the battery to make it safe for the ADC of a microcontroller to measure. Despite this it is important that we also add protection circuitry such as zener diodes or voltage clamps, to make sure the MCU and other sensitive components are not damaged. For the Analog-to-Digital (ADC) we would utilize the built-in ADC of our microcontroller.
Of course, when choosing the MCU itself we must make sure we consider the ADC resolution on it since it will directly affect the precision of the battery level measurement. We need to develop some software to program the MCU to read the voltage levels through the ADC and make the necessary conversions to get an accurate percentage reading.

There is another method to obtain the battery level known as Coulomb counting, where we measure the amount of charging exiting the battery over time. This way is especially effective for batteries with flat discharge curves since the voltage level changes very little until close to depletion.

To implement this method, we must design a current sensing device. Utilizing Ohm’s law, if we place a low-value resistor in series with the battery we can use the voltage drop across the resistor to find the current flowing through it. We can also use a Hall effect sensor which is a type of transducer that picks up any changes in a magnetic field and produces a voltage output that is proportional to the current. For the sake of simplicity, we would utilize the shunt resistor.

Table 3. Voltage Regulator Comparison

Feature	**Linear Voltage Regulator**	**Switching Regulator**
Operating Principle	**Uses a pass element to dissipate excess voltage as heat.**	Uses an inductor, diode, and a switch to convert and control energy flow efficiently.
Efficiency	**Lower, especially when the input voltage significantly exceeds the output voltage.**	Higher, typically between 80% to 95%, less affected by voltage differences.
Complexity & Cost	**Simple and low-cost with fewer external components required.** **Cost:** **Low-end: $0.10-$0.50** **High-end: $0.50-$3**	More complex and costly due to additional components like inductors and complex control circuits. Cost: Low-end: $0.50-$2 Mid-range: $2-$10 High-end: $10-$30
Output Noise	**-Typical noise levels for voltage regulators are as low tens of microvolts RMS (uVrms)** **- Low frequency (100 Hz or below)**	-Noise levels can range from a couple millivolts RMS (mVrms) to tens of millivolts (mVrms) -Higher frequency, due to switching frequency and its harmonics, ranging from tens of KHz up to several MHz
Thermal Management	**Often requires heat sinks or other cooling methods due to heat dissipation.**	Generates less heat, reducing the need for extensive thermal management.
Best Applications	**Applications requiring stable, clean power with minimal interference (e.g., audio, RF).**	Power-intensive applications where efficiency is crucial (e.g., portable devices, varied input voltage applications).

Now when it comes to the microcontroller, the method is slightly different. The MCU integrates the current flow over the time of measurement and considers the capacity of the battery; this is how we use current measurements to get the total charge that has been added or removed. We again need to introduce a software algorithm that updates a counter based on the current measurements and in turn, tracks the charge state. For an accurate measurement, we need to know the battery's total capacity in Coulombs or mAh and put it into the coding algorithm.

Table 4. Battery Level Measurement Comparison Part 1

Feature	**Voltage-Based Measurement**	**Current-Based Measurement**
Principle	**Measures the voltage across the battery terminals.**	Measures the current flowing in and out of the battery.
Complexity	**Relatively simple circuitry. Typically requires a voltage and ADC.**	More complex. Requires a current sensing component (e.g., shunt resistor, hall effect sensor) and often more sophisticated processing to integrate current over time.
Accuracy	**Directly affected by the battery's discharge curve; can be less accurate as it doesn't account for battery health or usage patterns.**	Potentially more accurate over the long term as it can account for actual energy usage and battery health.
Implementation Cost	**Generally lower due to simpler hardware requirements.**	Higher due to the need for precise current measurement components and possibly more complex software for calculating state of charge (SoC).
Suitability	**Suitable for applications where approximate level indication is sufficient. Best for scenarios with consistent load patterns.**	More suited for applications requiring detailed knowledge of battery usage and health. Ideal for systems with variable load conditions

Table 5. Battery Level Measurement Comparison Part 2

Feature	**Voltage-Based Measurement**	**Current-Based Measurement**
Impact of Load	**Load variations can significantly affect voltage readings, leading to less accurate battery level estimation.**	Load variations are accounted for in the current measurement, potentially offering a more consistent battery level indication.
Battery	**Highly dependent on the specific voltage discharge curve of the battery chemistry.**	Less dependent on battery chemistry for the measurement principle, but calibration might be needed for accurate SoC estimation.

One of the greatest uses of breadboards is the ability to assemble a prototype of an electric system before making a final PCB design. In doing this we can find any hiccups and iron them out before attempting our final design.

When prototyping a breadboard is basically a necessity since it enables rapid concept testing. This basically just means the fast facilitation from an early concept to a prototype since we can quickly assemble a circuit through using the breadboard. If we tried using a PCB for prototyping, we would find ourselves wasting resources like time and money. This rapid prototyping in the preliminary stages is great in making quick changes and improvements so we can achieve a more well-polished and efficient final design.

It is also important to understand that feasibility needs to be evaluated by building a physical circuit in a way that is cost-effective. By having a real circuit, we can test things like power consumption, signal integrity, compatibility of components and more. Breadboards give us a hands-on approach for ensuring a design's functionality before a more permanent and costly version. With breadboards we can also do component testing to see how different components react under real conditions and compare. This helps us make an informed decision on which components we want to have actually implemented into the final project.

Something we need to consider is which layout for our components and wiring will allow us to achieve the best, most efficient performance, limit interference, while having a compact design. With our breadboard prototype we can easily test different layout configurations. Similarly, debugging a circuit with a breadboard prototype is done easily since we have easy access to each individual connection and can test section by section to identify any problems; switching out components and changing connections to single out and fix any solutions are some more examples. This level of accessibility available for troubleshooting will ensure that we can swiftly figure out any kinks in our design, ensuring reliability and performance.

3.2 Part Comparison

Within our project's design, there are many different components communicating with each other to properly recreate a laser tag system. These components require extensive research in order to confirm that they connect and function properly. Some of the components that will be used will include a communication module, LCD display, haptic feedback, sensors, and LEDs.

3.2.1 MicroController Unit (MCU)

The microcontroller unit is the central part of our system that controls the different I/O peripherals such as RGB LEDs, motors, sensors, and displays. It is essentially the brain of the laser tag system, it's responsible for controlling the input and output operations of the laser gun and vest, managing the game's systems, and so much more. The choice of microcontroller and the software it runs can greatly affect the performance and features of the laser tag system. The software for this system will be written onto the microcontroller to allow us to have more flexibility and control over the system operations.

A microcontroller or MCU in simple terms is a miniature computer. This Microcontroller is made up of a central processing unit or a CPU that comes in many different shapes and sizes. This central processing unit is embedded with programs that can be run using input and output peripherals on the microcontroller. There are plenty of other important components that make up a microcontroller such as random access memory RAM or SRAM, clocks, flash memory, and much more these components are all connected to the central processing unit using an integrated circuit. These components all play a crucial role in what a microcontroller is and how it functions.

Microcontrollers work by being able to interpret data coming in through their input peripherals to receive data and let the code programmed by the user that is embedded central processing unit instruct which outputs are needed when inputs are detected. Easier said than done microcontrollers have many software functions that play a role in getting the inputs received to correctly output some of these include programs, interrupts, timers/delays, power modes, serial communication, channels, digital I/O, and analog I/O. Learning how to use these software functions is challenging as each microcontroller can have different integrated development environments or IDEs which can change how your software applications and development functions.

When doing research for our microcontroller we knew we had a few specifications, requirements, and features that are needed in our design. We need to make sure that the microcontroller we end up purchasing fits all of the features we need in our design, requirements for easy user operation, and specific specifications. Firstly a feature we knew that these microcontrollers needed to include is to be connected wirelessly to a central unit which would be run on a master computer. Taking that into account and the extensive research we did previously on wireless communication we decided that our microcontroller will need the ability to communicate via wifi technology. This means that to get wifi communication implemented into our microcontroller we have two simple options purchase a microcontroller that has wifi communication included or buy a separate wifi communication module that can connect to a microcontroller.

Another requirement we have for our microcontroller is its usability which often refers to the integrated development environment and the software applications it contains. Having an IDE that is easier to use or even if the user is more familiar with can make a huge difference in embedded software development efficiency and effective time spent. That being said one of the first things that must be looked at when deciding on an IDE is the programming languages it offers and which ones we feel the most comfortable operating. As students most of our experience in embedded system programming comes from the class we took which was taught to us in the C programming language this gives us a good familiarity with this language and will make using it easier. Another option we have is C++ this could be beneficial to C because of its many upgraded features including object-oriented programming, abstraction, libraries, and much more. When deciding on C vs C++ we must take into account a few things first off C++ is not much different at all from C so using it should still feel fairly familiar secondly we must weigh the advantages that C++ could bring us compared to C and decide how important they are and if they are needed enough to decide to use a less familiar language. When deciding on a microcontroller another important thing we must include is the IDE code editor's ease of use by using an easier to operate on and understand IDE we can save a lot of time trying to debug our code.

Lastly, our microcontroller must have specific specifications that match what we need in our project or what we can assume that we will need in a worst-case scenario. Setting a proper minimum standard for microcontroller specifications is crucial because if we don't do the research we may end up buying four that aren't good enough in certain aspects and end up wasting upwards of fifty dollars. That being said since we haven't built the project yet it is very hard to assume exactly what specifications we will need without knowing what type of extra features we may try to include as we are building. Therefore it is logical to overcompensate for what specifications we expect to need just in case to make sure that situation never occurs. The first and most important specification we need to worry about is the size and shape of our microcontroller it needs to be able to fit safely into a small section of a portable gun. This means we must buy a microcontroller that is smaller in size to be able to fit into a compact area, it may be beneficial to get a longer microcontroller with minimal width due to the gun shape which has plenty of length but a limited amount of width. Another specification is the amount of general-purpose input/output or GPIO pins we need so we can connect to all of the inputs and outputs our design may incorporate. Although we may never use them all it's safe to assume that we will need a minimum of sixteen GPIO pins to make sure that we won't ever run out while adding things to our design. Lastly, the specific specifications such as the CPU, ROM, SRAM, and flash are all extremely important to how the microcontroller functions including its efficiency and speed.

The MSP-ESP430FR6989 is a microcontroller built by Texas Instruments. This board has a lot of features that stand out from a normal microcontroller including a liquid crystal display or LCD built into the microcontroller. With great specifications, this microcontroller could easily run the code we needed for our project. This microcontroller was chosen as one of our options because most of our team had to buy one in the past for our classes which means we already have a few to start with. This however becomes pretty negligible because of the price of the MSP430 if we need four microcontrollers for our project it's almost cheaper to buy four new ones than it would be to get another MSP430. Also, this microcontroller does not include built-in wifi or wireless communication of any kind which means to connect wirelessly we would need to spend more money to buy a wireless component. Also, this microcontroller is fairly large and would most likely not fit in our gun design anyway making this option not as useful as we once thought. However, they aren't completely useless in fact they will still be put to good use because since we already have them they can still be used for individual testing of components.

When you think of a small board you can include in your project you may instinctively think of the Raspberry Pi. This however isn't actually a microcontroller at all its a single-board computer or SBC which means it can run general-purpose computing and operating systems such as Linux. Raspberry Pi also comes with wifi which means we will not need to buy a separate component for wireless communication. However, since it comes with so many extra features this comes with some trade firstly the price of a Raspberry Pi is thirty-five dollars meaning if we need to buy four we are spending one hundred and forty dollars which is way above our budget. The size of the Raspberry Pi isn't too big however it is not small enough to comfortably fit inside our gun design which could give us some trouble trying to design the gun with room for it. Overall the Raspberry Pi has great attributes and although it may be a great option for some projects it's just too expensive and too big for our design.[10]

Arduino is one of the most popular microcontrollers on the market today and for good reason. This is because of its open-source platform which allows users to share their code online for free and others to use and modify shared codes which brings more developers into the Arduino community. This paired with an extremely user-friendly IDE that simplifies the software design process for any level of user from beginner to expert makes this microcontroller so popular. The Arduino comes with great specifications that can run the code required in our project with no problem. The Arduino also comes in many different shapes and sizes with the smallest being the atto model which is 0.45" x 0.40" these Arduino models come in some very small sizes and can easily fit inside our design. However, the only issue with this is the lack of wifi or any wireless communication which means that with the price of the Arduino and the price of adding a communication module for four microcontrollers, it will be easily over a hundred dollars and out of our budget.

The ESP32 is a microcontroller developed by Espressif Systems and is known for having one feature that most microcontrollers don't have. This is a built-in wireless connectivity that includes wifi and Bluetooth communication. Another great feature of the ESP32 is that it runs on the Arduino IDE which has a great user interface that will help us code more efficiently. This model is sold by many different companies and has many different versions each having their advantages and disadvantages. This makes it hard to pick out an appropriate model because each comes with certain specifications that may be more useful than others. For the most part, we are looking for a board that has enough GPIO pins to successfully connect to any amount of inputs and outputs we may try to include in our project. It must also be the correct size to comfortably fit into our gun design and have mounting holes to keep it in place for intense games. This has to also be done with good enough specifications to run any type of code we may throw at it. After researching the ESP32 it fits every criterion that we could need in a microcontroller for our project and even better it's extremely cheap after looking at each and every place selling we found some for seven dollars.[11]

Table 6. Microcontroller Comparison

	ESP32	**MSP430**	**Raspberry pi**	**Arduino**
Price	$3.80	$10.77	$10.00 - $80.00	$9.00
Wireless Connectivity	Wifi and Bluetooth	None	Wifi and Bluetooth	none
IDE	Arduino, VS Code	Code Composer Studio	Any	Arduino, VS Code
Languages	C,C++,MicroPython	C and C++	Python	C, C++

3.2.2 Power Supply Unit (PSU)

Battery level management is another important goal to implement the design of the Power Supply Unit. To design the power supply unit, we will be using a voltage regulator, diode, and capacitor. We use the voltage regulator so that the electronic components in our system can utilize the voltage from the battery. The diode rectifies the voltage that is drawn from the battery. Lastly, the capacitor filters out any AC components. The PSU will also have its own smaller PCB. We expect the PSU to offer an approximate 1 hour of playtime and produce a minimum output of at least 7 volts. Possible options for the battery are a 2000 mAH rechargeable battery pack from Amazon or possibly simple AA batteries.

Diving in deeper into the different options for the Power Supply starting with the USB Power Bank. Portability is one of the most important features that is desired for the power supply since a laser tag system requires constant mobility and extended range. An external power bank offers that ability and allows the player to take the game to wherever they desire. One of the main advantages of the power bank would be its flexibility when it comes to the power options, for a power bank can come in many different capacities. The reason this is beneficial is that we can select the perfect size to match the system’s power needs and our desired time of operation. Additionally, an external power bank can be recharged easily and quickly using USB charging; convenient for charging overnight or in between games. Power banks operate at a low voltage which makes them safe to deal with and have little risk of electrical hazards, unlike higher-voltage batteries. When compared to a more complex power system a power bank can end up being relatively inexpensive, the price is also a static number. Furthermore, a power bank offers simplicity when it comes to wiring since there is no need for complicated wiring and infrastructure if we were dealing with a fixed power source instead. An added benefit is a cleaner appearance and a user-friendly setup. As a result of all these benefits, we get an improved player experience due to the consistent and powerful nature of the USB power bank.

Alkaline AA batteries support many of the same benefits as the power bank with a few key differences. AA batteries are much easier to source since they are widely available at many retail stores and can easily be bought in bulk amounts. For economic reasons, AA batteries offer a very low startup cost and convenience for any system that is not used consistently. Another clear benefit of the AA batteries over the power bank is even more added simplicity as there is no need for a recharging system and it offers an even quicker turnaround between games. Finally, the last main advantage of AA batteries would be the ease of disposal as AA batteries do not have any special disposal requirements.

Lithium-ion rechargeable AA batteries are very similar to both the previous options but there are some key differences to look at. For example, despite rechargeable AA batteries being widely available they are not as readily available as a normal AA battery, especially in bulk quantities. Now, when discussing pricing options, AA batteries offer the lowest start-up cost, but when considering longevity, rechargeable batteries offer a much more cost-effective solution. The rechargeable batteries offer convenience in their reusability, unlike normal AA batteries which need to be constantly replaced. The rechargeable AA battery also greatly reduces the amount of waste but does require a special method of disposal at the end of its life cycle. Overcharging and deep discharge must be considered with rechargeable batteries, unlike regular batteries. Another benefit of lithium-ion over alkaline is it boasts a higher capacity voltage typically around 1.5V or 3.7V, so lithium-ion batteries support a longer battery life. This is an important aspect to look at for laser tag devices since they tend to have a high drain. With a laser tag system, the self-discharge rate is another feature that is worth looking at since there can often be a lot of downtime between games; rechargeable batteries lose less charge when not in use when compared to the standard AA battery. When considering the compactness of each option the AA and rechargeable batteries are much better than that of a power bank; this can help in keeping the system small, allowing for a pistol-like design.

Table 7. Power Supply Comparison Part 1

Attribute	**USB Power Bank**	**AA Batteries**	**Li-ion (AA) Rechargeable Batteries**
Availability	Different capacities may be more difficult to get a hold of.	Readily available and can be purchased in bulk in any retail store.	**widely available as well but not as much as normal AA batteries.**
Price	Highest cost to start but due to rechargeability is cost-effective with time.	Lowest initial cost but needs constant replacement.	**Middle ground between power bank and AA batteries and cost-effective over time.**
Convenience	Recharging is required but offers the longest operation lifetime out of all options.	No charging is needed, and replacement is fast.	**Also needs recharge but also has the benefit of reusability.**
Power Management	Can offer sophisticated power management options and higher capacities for extended use.	Simple power solution without the need for electronics for power management.	**May require integrated circuits for charging and power management in the device.**
Environmental Impact	Rechargeable, reducing waste. Proper disposal required due to battery chemistry.	Disposable, contributing to environmental waste, though free from heavy metals.	**Rechargeable, significantly reducing waste. Requires proper disposal at end of life.**
Performance Consistency	Consistent performance with regulated output until depleted.	Performance gradually declines as the battery discharges.	**Generally offers consistent output and higher energy density, with performance maintained until depleted.**

Table 8. Power Supply Comparison Part 2

Attribute	**USB Power Bank**	**AA Batteries**	**Li-ion (AA) Rechargeable Batteries**
Safety	Generally safe with built-in protection circuits, but requires care in handling to prevent damage.	Considered very safe under normal conditions.	**Safe, but requires protection against overcharging and deep discharging.**
Rechargeability	Yes, designed for hundreds to thousands of recharge cycles.	No, designed for single use.	**Yes, can be recharged hundreds of times.**
Capacity	High capacity and can output various voltages.	Fixed voltage (1.5V per cell), limited capacity.	**Higher capacity than alkaline, fixed voltage (typically 1.5V or 3.7V for Li-ion cells, but regulated in AA format).**
Weight and Size	Potentially heavier and larger, depending on capacity.	Lightweight and compact.	**Similar in size to alkalines but slightly lighter, offering better energy density.**

After considering all options for the power supply the most balanced and capable option is the Lithium-ion AA rechargeable batteries. The main advantage that makes this option the best is that like the USB power bank, the lithium-ion batteries are rechargeable while still being compact and cheaper than the alkaline batteries. The design of the laser gun can remain relatively small while still being much more cost-effective and less wasteful than normal AA batteries. While the power bank did offer the longest playtime of all the options, the lithium-ion still supports a longer play time than the alkaline due to its superior energy density. Furthermore, these batteries output a consistent voltage level, which is important for the system to properly operate. Putting it all together, the choice of lithium-ion batteries offers the best options for a power supply that meets our goals in a way that is sustainable, cost-efficient, and creates a high-performance laser tag experience. [2]

3.2.3 Emitter

The main aspect of our project is the laser. This consists of a gun with a 5mm IR LED which emits infrared light when the trigger is pulled; this is perfect for trying to emulate the function of a real gun without the dangers that a real gun consists of when doing a simulation. The IR beam emitted can contain unique frequencies that can help with player identification and other useful information critical to the game. Even though we have mainly chosen an infrared LED to proceed with our project, we will still analyze the different advantages and disadvantages of using infrared lasers, LEDs, and lasers.

Table 9. Laser Comparison

Features	**Infrared Lasers**	LEDs	Lasers
Light Emission	**Infrared Light**	Visible Light	Visible Light
Beam size/characteristics	**Narrow beam based on additional lens**	Narrow or wide beam based on design	Narrow beam based on additional lens
Wavelength	**~850 nm**	Various wavelengths depending on LED types	532nm green, 650nm red, 405nm blue
Cost	**$0.28**	$0.16	~$0.65
Visibility	**Invisible to the naked eye**	Visible to the naked eye	Visible to the naked eye
Safety	**Can be hazardous if directed straight to the human eye**	Generally safe	Can be hazardous if directed straight to the human eye
Battery consumption	**1.5 to 3 volts**	1.8 to 3.7 volts	2 to 5 volts

LEDs are typically seen used in TV screens, household lighting, or even light effects around your house. They are typically a wide beam meant to light up a large amount of area, but this can be focused in a beam by using a certain-sized lens meant to focus the light into a straight beam. This is usually not as dangerous as compared to the other options but could introduce the issue of possible heat at the focal point of the light. For this project, we decided to proceed with other options and utilize LED lights for different aspects of the project. Such aspects are visual indications of being shot or possible visual indications that you are firing your gun.

Lastly, the last option is using a visual red or green laser to fire the gun. This is a good option as it is already usually set into a beam shape and is also visually seen by the naked eye. Typically this is used as an attachment to a gun to visually see where the gun is directed but as seen in other projects using lasers, it could be used as an emitter to a receiver to indicate possible hits made by the user. However, due to its high cost and possible dangerous factors, it could possibly cause harm to the users and those around them. We decided to proceed with the other options to emit light.

Infrared lasers are the types of light-emitting part that many different laser tag products typically uses. Typically is usually used due to its low voltage consumption and ability to encode bits in the light it emits. Also, its ability to be invisible to the naked eye is typically preferred over a visible laser due to not wanting to have multiple lasers seen on a battlefield going between the two groups of users. But with all these advantages there is still the danger of it being possibly harmful to the human eye, typically with other light you are able to notice when light is being directed at your eyes. Due to infrared lasers being invisible, it is hard to notice when the laser is being directed at your eyes, and with increased exposure over time, it would cause irreparable damage to your eyes.

In conclusion, we as a group decided that infrared lasers were the option to utilize for our project. Due to it high demand in the laser tag industry, there would be a lot of support and external resources to utilize to better understand how we would use infrared lasers to emit a laser beam to the receiver for this project. Also, due to its low power consumption and low cost, it would sufficiently achieve everything that we need to have for our project and also fit well within the budget that we made for the project. We will proceed with caution to avoid any possible dangers that could be experienced when using the infrared laser and also properly go over any engineering standards required when using a laser for a project.

After concluding that we will utilize infrared light as the main source of light emission for our project, we will also explore and research the different advantages between T1 and T2 infrared emitters. The decision between these two emitters is important due to making sure that all emitters are the same to prevent possible compatibility issues when producing the project. Also even though there aren't many differences, there differences that exist will affect the overall design of the project. Each one of these emitters contains different advantages and disadvantages and further research below will decide which one of these emitters would be better fitted for our project.

Table 10. Infrared Emitter Type Comparison (T1 or T2)

Features	**T1**	T2
Durability and Reliability	**Greater durability due to having a smaller construction but similar reliability**	Lower durability due to having a larger construction but similar reliability
Energy Efficiency	**Higher energy efficiency is 20% more efficient than T2**	Lower energy efficiency needs 20% more power than T1
Strength and Power	**Lower strength and power is about 20% less powerful than T2**	Greater strength and power being about 20% more powerful than T1
Safety	**Safer than T2 due to lower power**	Less safe than T1 due to the usage of greater power
Scalability	**Easily able to purchase more and an already well-established type of infrared emitter**	Harder to purchase as compared to T1 due to being fairly new in the market
Production and Support	**More support due to being an already well-established emitter**	Less support due to being a new type of emitter
Compatibility	**The same as T2**	The same as T1

When considering the choice between a T1 and a T2 emitter for this project, there are several aspects to consider beyond just the simple size and cost of the emitter. These aspects can be seen in the table above and the explanation of each aspect can be seen below describing the reason why each aspect matters in deciding the infrared laser type.

1. Durability and Reliability: Durability and reliability a very important aspects to consider due to the possibility of playing in many different conditions. The ability to utilize the product in any situation is vital to the efficiency of the product. The emitter is expected to function not only indoors but also outdoors which would result in different varying temperatures, humidity, and light levels. Also, the durability will be largely considered due to the potential physical impacts when using the product.

2. Energy Efficiency: The power consumption of the emitter has to be considered when calculating the pros and cons of the two different emitters. This is important due to its effect on the overall design of the gun. Also, the efficiency in the power

consumption would allow us to use a cheaper and lighter battery when designing the product.

3. Strength and Power: The strength and power of the beam a very important factors to calculate as the laser gun needs to function from long distances and also be reliable at the same time. A beam that spreads out at farther distances will not be reliable enough at long distances while a very narrow beam will not be reliable in up close situations also known as CQC or close-quarter combat.

4. Safety Concerns: Safety when using laser beams needs to be considered as a major aspect as there should be no harm done to the user when using our product. This is particularly concerning with eye safety as a strong laser beam can cause damage to your eyes.

5. Scalability: Scalability in the efficiency of producing in bulk needs to be considered in the case where the product needs to be produced in bulk for the market. Ease of access and also bulk pricing could be possibly considered when looking into the possibility of using either emitters.

6. Production and Support: The support and production of the emitters need to be considered as without proper support the utilization of the emitters would be considerably more difficult. And at the same time if the manufacturer stops producing the emitter that we have tested with then we will run into the problem of not having a stable manufacturer to purchase the emitter from.

7. Compatibility: The compatibility between the emitter and sensors is largely important since without proper compatibility the project will not function properly. This will be the most important factor that we have to consider when choosing the emitter.

By weighing these different aspects and factors alongside the basic considerations of size, range, and cost, we decided that a T1 would be the best option for our project. This decision was made based on the wide availability of T1 infrared emitters in the market making it easy to gather and purchase. Also due to being a fairly old type of emitter there are many guides and supports explaining or assisting possible troubleshooting issues that we experience while working on the project.

3.2.4 Infrared Receiver

Integrating Infrared Receivers into the vest for hit detection from infrared light-emitting laser guns is very important in simulating combat scenarios. The use of sensors is vital to this project and many different factors and aspects need to be considered when choosing what infrared receivers to use when creating our project. These aspects and factors will be vital in creating an immersive experience for the users and allow better tracking or precise performance when using the system.

When selecting an infrared receiver, it is crucial to weigh various factors such as sensitivity to ensure reliable detection under the different conditions the user will play in. The pros and cons would need to be considered to further enhance the user's immersive experience. Some of these factors and aspects can be seen below.

1. Sensitivity: The sensitivity of the receivers needs to be largely considered since this will be vital to the project's functionality. A lower sensitivity would result in less precise experiences and could introduce problems where the laser beam should have hit the user but the sensitivity is too low to sense the laser. Also at the same time, too much sensitivity would cause false positives where the user is registered to be hit by a laser shot that clearly would have missed them.

2. Response time: The receivers are expected to have short response times to allow a smooth and clean immersive experience for the user. It is vital to have a good response time due to possible situations where instant feedback is necessary to replicate a realistic combat situation. Such situations could include close-quarter combat where instant feedback is necessary to show whether you are alive or dead in the intense situation.

3. Cost and Production: The cost and production of the receivers need to be considered when choosing what to utilize. Since many sensors are needed to properly scan 360 degrees around the user the sensors must be cost-effective and not too expensive due to the large quantity that we need to use for the project. Also, it is vital that the production of the sensors is reliable to prevent issues where the manufacturer has stopped producing the sensors that we decided to use.

4. Reliability: The reliability of these sensors needs to be considered as the sensor is expected to function in different conditions when using the product. The design needs to allow better sensitivity in different conditions and also help reduce false positives from other sources.

5. Durability: The durability of the sensor needs to be largely considered when deciding which sensors to use. Since the user could be expected to be in a very intensive situation, it is vital that the durability of the sensor would support the user in being reliable and would not break in cases of physical impact.

6. Wearability: The wearability of the sensors needs to be considered when choosing what sensor to use. The sensor needs to be light enough and small enough to be attached to the vest without causing any issues with movement and range of mobility of the user. As such the size and weight of the sensors would need to be considered not only during the choice of which sensor to use but also the overall design of the product.

7. Power efficiency: Efficient power management is crucial especially since the vest and sensors would be battery-operated. A sensor that utilizes too much power would cause issues when choosing the proper battery to use for the vest. Also if

the sensor uses too much power then the amount of time the vest would be able to function would largely be decreased and it would not achieve the expected specification that we have set for the project.

8. Maintenance: Just like other components in the project, the sensors need to be simple enough to be easily replaced or maintained to ensure a clean and immersive experience for the user. A sensor that is too complicated would result in difficulties when troubleshooting and also include possible maintenance issues when trying to fix the vest.

By carefully considering these aspects and factors, we will be able to properly make an informed choice when deciding what sensors to use for the project. These requirements or technical aspects will be vital in creating and enhancing the overall user experience for the project making the whole system more engaging.

When considering which receiver emitter we will purchase for the project, there are two different types of emitter we can purchase for the infrared receiver. These two types are the photodiode and the phototransistors which both have their own usages, advantages, and disadvantages. These differences need to be analyzed and researched to better understand what type of emitter we should purchase for our project and also the type purchased would largely affect the overall design of the PCB.

Table 11. Infrared Reciever Type Comparison (Photodiode or Phototransistor)

Features	**Photodiode**	Phototransistor
Purpose	**A semiconductor device containing a p-n junction that receives infrared light that generates a current when exposed to infrared light**	A semiconductor device containing a base, emitter, and collector that can generate a current proportional to the intensity of the light
Sensitivity	**Higher sensitivity compared to phototransistor ~0.4 A/W to ~0.9 A/W**	Lower sensitivity compared to photodiode ~50 A/W to ~1000 A/W
Response Time	**~1 microsecond**	~100 microseconds
Power Consumption	**5 V**	3 to 20 V
Size	**1mm, 1.5mm, and 3mm**	5mm
Cost	**~$0.73**	~$0.85
Safety	**Lower risk of electrical shock**	Higher risk of electrical shock due to a higher voltage

Photodiodes or simply just diodes are infrared receivers that are semiconductor devices that receive infrared light when forward biases meaning that there is an application of a voltage across the diode in a way that allows current to flow easily through the diode. They are similar in structure to basic LEDs but specifically made to receive infrared light instead of visible light. They are typically used in situations where invisible light is required such as proximity cameras, security cameras, night vision equipment, remote controls, and many more. They also boast a very small size allowing you to use the diode in any situation. They are also more simple in design making it very easy to include into your design and also introduce fewer possible areas of failure when using the diode. Overall photodiodes can be seen used in many different household commercial products such as remote controls and it stands to be a very simple way to receive infrared light for our laser gun project.

Phototransistors are similar to photodiodes in that they are sensitive to infrared light and are meant to receive and detect infrared light. It also combines the functions of photodiodes and a bipolar junction transistor or BJT in a singular package. This functions as a way to output a photocurrent proportional to the intensity of the infrared light. This allows you to easily tell the distance that the infrared light has traveled and therefore possibly calculate game information to process through such intensity. This will simplify the overall circuit in the final design by decreasing the necessary space for a BJT by combining it with the photodiode. But due to its ability to combine both components, it will overall take more space when receiving the light. It also gains the ability to amplify the current allowing better detection and signal processing when using it for the project. Overall it proves to be a more modern solution to a simple circuit of using a photodiode with a BJT.[22]

In conclusion, we have decided to utilize the photodiodes in our laser gun project. This decision was made by the fact that we do not need to detect the intensity of the infrared light. The project we have designed and planned only simply needs to detect whether the receiver has detected any sort of infrared light and simply output that it has been sensed. The use of a phototransistor will add extra complexity to our project which could possibly fail when designing and creating the final product. However, due to the many advantages that a phototransistor contains, we will keep in mind the possibilities that a phototransistor will add to our project and possibly create a stretch goal that will utilize phototransistors to detect the intensity of the infrared light. Overall for our project we will use photodiodes to receive infrared light due to its simplicity, overall small size, and ease of purchase.

3.2.5 LCD Display

In laser tag in order to make the gameplay as interactive as possible, a display will be used to show important information to the player. Key information such as the amount of ammo left, scoreboard, player’s health, and player's record (kill/death ratio). A display will allow for a better gameplay experience between both players and overall a useful peripheral that facilitates the core of the laser tag.

The LCD1602 is a character-type liquid crystal display that is 16 by 2 in resolution. This is controlled by the MCU and will display information provided by the Bluetooth modules. The MCU module will be able to receive information from its counterparts when a laser receiver has detected a hit; and then will update the kill counter. Furthermore, it will keep track of the ammo capacity of the laser guns and when the user should reload. For the LCD1602 to display correctly, GND must be connected to a resistor, this value will determine the contrast for a clear and visible display.

In a laser tag game, real-time feedback is crucial for an immersive and interactive experience. Some options in this category that are worth considering are LCD(Liquid Crystal Display) and OLED(Organic Light Emitting Diodes) displays. LCDs are generally more affordable and offer better peak brightness, making them suitable for use in bright environments. On the other hand, OLEDs offer superior contrast, color accuracy, and viewing angles, making them ideal for high-end devices and applications where image quality is important. For our laser tag system, we plan on using the LCD display because it is cost-effective, more durable, easier to access, and has a lower power consumption. LCD displays like the 16x2 LCD1602 are widely available and come in multiple sizes and configurations. This makes it easier to find a display that fits the specific needs of the laser tag system. A 16x2 LCD display works by controlling the liquid crystals to either block or allow light to pass through, creating characters and symbols on the screen. It's controlled by sending data and commands to its controller, which in turn manages the display of information. The display can serve as the primary interface, bridging the player and the game system. Providing immediate feedback and important game statistics.

1. **Ammo Count:** the display can show the remaining ammo in a player's gun by tracking how many times the trigger has been pulled. This adds a strategic element to the game as players must take into account their ammo and use it wisely.

2. **Health Points:** The player's remaining health points can be shown on the display. This can create suspense and excitement as players are aware of their health and they try and avoid getting tagged.

3. **Scoreboard:** The display can show current scores, depending on the game mode. It can have a leaderboard aspect creating a competitive environment and allowing the players to know their standings for the game's duration.

4. **Player's record(Kill/Death Ratio:** The display can track each player's performance. In addition to the scoreboard, in shooter games, an important metric that can separate decent from good players is the kill/death ratio. Players will be motivated to maximize this number as much as possible to rank high on the scoreboard.

The LCD1602 is a 16x2 character-type Liquid Crystal Display (LCD) that can display letters, numbers, and special characters. It's controlled by a microcontroller unit (MCU) and can display information provided by the Bluetooth modules.

1. **Hit detection:** When the laser detects a hit, the microcontroller unit on the player's vest receives this information and updates the kill counter on the opponent's display.

2. **Ammo tracking:** The microcontroller unit keeps track of the ammo capacity of the laser guns. When the ammo is depleted the display can prompt the player to 'reload', adding another layer of realism to the game.

3. **Contrast adjustments:** For the LCD1602 to display correctly, the Ground (GND) must be connected to a resistor. The value of this resistor determines the contrast of the display, ensuring clear and visible information.

A 16x2 LCD has two registers, command and data. The register select is used to change between registers. Whereas RS = 0 is for the command register and RS = 1 is for the data register.

The command register stores a variety of command instructions given to the LCD. For example, clearing the screen, initializing, and controlling the display. The Data register stores the data that must be displayed on the LCD. It uses the ASCII value of the character to display on the LCD. When data is sent to the CLD, it goes through the data register to be processed.

3.2.6 LED

In many laser tag systems, RGB LEDs are installed in each sensor block on the player's vest. When the player is hit a system of green LEDs turning red can visually show that the player has been hit. These LEDs can also be used to indicate which team the player and its opponents are in. In addition to indicating when a player's been hit LEDs can also be used to indicate different game states or game modes. For example, a quick draw game mode where both players' LEDs are red to start off and light up green to indicate 'go', then whoever is shot first will turn red again. Peripherals like LEDs are a great way to enhance a player's gameplay and immersive experience, accompanied by motors for vibrations and other sensors, it makes for a truly captivating system.

In our laser tag system, a player's vest will be equipped with many different components to enhance their experience. The vest will consist of a microcontroller and an array of red and green LEDs in each block of receiver and vibrators.

Focusing on the LED, this is a great addition to give visual cues in parallel to the physical tactile feedback that the player you shot at has been hit and even the player that has been hit can visually see that they've been marked red. This addition is inexpensive since LEDs in bulk are cheap. It is also easy to program with any microcontroller. The receiver would detect a signal from the IR emitter from the opponent's gun and that signal would be used to turn off the green LEDs and turn on the red LEDs, indicating a tag.

1. **Hit Indication**: When a player is hit, the green LEDs on their vest turn off and the red LEDs turn on. This immediate visual feedback makes the game more immersive and helps players quickly understand the game dynamics.

2. **Status Indication**: LEDs can also be used to indicate different states of the game or the player. For example, blinking LEDs could indicate that the player is 'respawning' after being hit, giving them a few seconds to find cover.

3. **Ammo and Health Indicators**: Different color LEDs can be used to indicate the remaining ammo or health points of a player. This adds a strategic element to the game, as players must keep an eye on their ammo and health status.

LEDs are a cost-effective and easy-to-implement component that can significantly enhance the gameplay experience in a laser tag system. They provide real-time visual feedback to the players, adding an extra layer of interactivity to the game.

3.2.7 Haptic Feedback

Another aspect of human-machine interaction that goes under the radar is Haptic Feedback. Most people don't realize it but the phones we use every day while we type, and long press have tactile feedback that makes it immersive for the user. Similarly, in Laser Tag, feedback is very important; this allows the user to be able to feel the laser gun shooting and know when they got hit. This feedback can make the game more realistic and engaging.

Motors can be used to generate vibration or movement while tactile buttons can provide a distinct 'click' sensation when pressed. These elements can significantly improve the intuitiveness and the overall responsiveness of a device.

Now the question is which haptic feedback motor would be the best fit for a laser tag system? To answer this, we need to look at the different haptic feedback motors and what pros and cons each option offers. The different motors we will be discussing are the following: Eccentric Rotating Mass (ERM) Motors, Linear Resonant Actuators (LRAs), Piezoelectric Actuators, Voice Coil Actuators, and Shape Memory Alloys (SMAs). Different aspects we will be looking at for each motor are reliability, cost-effectiveness, simplicity, compactness, and much more.

Starting off, we are looking at the Eccentric Rotating Mass (ERM) motor and its benefits and drawbacks. First, we need to explain the functionality: an ERM is an electric motor with an off-center weight attached to the shaft of the motor. What this does is when the motor shaft is rotated, because the weight is unbalanced, the "rumble" or vibration sensation is created for the system. The clearest and most notable upside of an ERM is its simplicity and price; creating and implementing an ERM is a very simple process therefore making them one of the cheapest options for the haptic system. An added advantage of their simple nature is how robust they are since there are not too many moving parts, being able to withstand plenty of use with not much wear and tear. In situations where stronger vibrations are desired, ERMs are usually chosen since they can produce heavy vibrational force. Some drawbacks include the limited vibrational patterns and intensities that these motors can provide. The time at which the motor can physically spin the weight to generate the vibrations can take a significant amount of time when compared to other haptic feedback systems. Power consumption also tends to be quite high in these systems. Larger size, heavier weight, and more noise tend to be higher in ERMs as well compared to most other vibrational systems. These types of motors are commonly used amongst gaming controllers due to their low cost, and sometimes in the automotive industry for their powerful vibrations. The ERM motor can possibly be a good fit for the laser tag system due to its cheapness, simplicity, and durability but size and weight need to be considered for the compactness of the system; the lack of feedback range that can be achieved with an ERM motor must also be considered.

Another viable option for the haptic feedback system is a Linear Resonant Actuator (LRA) motor. An LRA motor works by attaching a magnet to a spring with an electromagnetic coil surrounding it. The vibrations are created through the coil that drives the motor to move the weight inside. The key difference between an LRA motor and an ERM motor is the ability to provide a much more defined haptic response with more patterns and intensities. This would help in creating a better player experience for the laser tag system, specifically in being able to have different haptic responses for different scenarios. LRA makes it possible for an even more compact and thinner design over ERM which helps in our goal of making the laser gun as compact as possible. Added benefits an LRA motor offers are energy efficiency, when operating at their resonant frequency, and quieter operation. There is generally an increase in the cost of LRAs over ERMs which may make it less suitable for this project due to our limited budget. Due to its complexity, achieving the full range of feedback from an LRA involves more complex control systems which also leads to an increase in cost and design. The durability of the LRA, while good, is still less desirable than that of a standard ERM and is more susceptible to wear and tear, especially through rigorous use. One thing that must be considered is how we are limited to the resonant frequency needed to make sure the LRA is operating at its full capacity. Everything considered, while being possibly more expensive and complex than the average ERM system, the faster response time, a wide range of haptic feedback, and a more compact design may make it the perfect choice for our laser tag system.

A more interesting option would be a piezoelectric actuator which utilizes the reverse piezoelectric effect to create micromovements and vibrations. The piezoelectric effect is when we create an electrical charge when a certain material receives a mechanical movement usually in the form of pressure; this effect also works in reverse which is how we create the vibrations and 'rumble'. Because the supplied voltage to the actuator is directly proportional to the amount of motion that is created, we can achieve very precise control over how much movement and vibrations we are producing. This precision is the main advantage of the piezoelectric and would allow for well-defined haptic feedback with the ability to give the player a truly immersive experience. The other major benefit of piezoelectric actuators is its uber quick response time which is faster than that of an ERM or LRA motor. Additionally, because power is only consumed when the state of the actuator is being changed, we have a very energy-efficient product for a battery-powered device. Due to the lightweight and small size of the actuator, they are ideal for portable or wearable devices. One clear downside of using piezoelectric is the cost, it is a much higher cost to use over the normal ERM and LRA. The implementation would also be much timelier and would require more complicated control electronics to regulate the voltage for precise operation. Fragility is also a concern for the piezoelectric actuator since the materials required are not very strong and can be vulnerable to bending and impact. Despite its much higher cost, complex implementation, and moderate durability the piezoelectric actuator is still a very good option since it meets and exceeds the requirements for our laser tag system. For example, the piezoelectric's very compact design would be perfect for the laser tag vest and the super-fast reaction time and high control would greatly enhance the user experience.

After weighing out the possible haptic feedback motors to integrate into our senior design project, we have decided that the best possible option is the Eccentric Rotating Mass (ERM) motors. This decision comes from the balance of the total cost, the complexity of implementation, and the tactile experience provided by the ERM. The ERM hits all the marks necessary for the use of the laser tag system and does it in a way that is still cost-effective. Despite its counterparts offering a more fine-tuned and variable experience we could not justify the difference in cost for the slight increase in quality. A relatively easier implementation is also crucial in order to make sure we can keep up with our schedule and stay within the budget. The main benefits of the Linear Resonant Actuator and Piezoelectric actuators don't fully align with the major necessities of our laser tag system while the ERM meets all the requirements and does it efficiently. The ERM motor ensures that we can achieve clear and immediate feedback to the player, still maintain a compact design, and overall enhance the user experience while still keeping a simple design and not inflating our total cost. Through this choice, we can deliver what we promised which was an immersive laser tag experience while still meeting our performance and budgetary goals.

Table 12. Haptic Feedback Comparison

Feature	ERM Motor	LRA	Piezoelectric Actuator
Principle	Rotating mass creates vibration	Oscillating mass creates vibration	Electric charge induces shape change
Feedback Variety	Low	Medium	High
Response Time	Moderate	Fast	Very Fast
Precision and Control	Low	Medium	High
Cost	Low	Medium	High
Size and Weight	Depends	Compact	Super Compact
Implementation Complexity	Low	Medium (requires matching resonance frequency)	High (requires complex drive circuitry)
Durability	High	High	Moderate
Typical Applications	General consumer electronics	Devices requiring precise, localized feedback	Medical devices, precision machinery

3.2.8 Communication

Laser tag has a variety of hardware accompanied by great software that allows successful function. One of the most important factors of the gameplay is wireless communication between the players. Assuming that there are two players with each two guns, the system must accurately and efficiently update with reasonable delay in order to maintain plausible results. There are many choices of wireless communication available today each with its own pros and cons. Some include Wi-Fi, Bluetooth, wireless LAN, and much more.

Communication is one of the most important aspects of creating anything wireless. In a wireless laser tag system, it is further expressed by the need to have an immersive system for players. To make the game immersive several requirements must be met, such as latency: laser tag is a fast-paced and physical game that requires fast thinking and movements as well as fast processing and communication. Different communication protocols among popular devices are Universal Asynchronous Receiver/Transmitter(UART), Inter-Integrated Circuit(I2C), and Serial Peripheral Interface (SPI). They are commonly used for communication within an embedded system for their ease of use. They all accomplish the same goal of transferring data and communicating but they have differences, each with their advantages and drawbacks. It is up to the engineer to decide what is prioritized and important to make their choice.

Universal Asynchronous Receiver/Transmitter or UART is one of the earliest serial protocols used in devices using serial (COM) ports, modems, and RS-232. It is simple and easy to use, it defines a protocol for exchanging serial data between two wires. UART only uses two wires between the transmitter and receiver, they can both receive and transmit in both directions. Communication can be simple: Data is sent in one direction only; half-duplex: Each side transmits but one at a time, and finally full-duplex: both sides can transmit and receive simultaneously. A big advantage of UART is that it is asynchronous, the transmitter and the receiver do not share a common clock. This simplifies the protocols but in turn, causes certain requirements. Both devices must transmit at the same speed, measured in baud rates, some of the most common baud rates are: 4800, 9600, 19200, 57600, 115200. Both sides of the UART connection use the same frame parameters. A UART frame format consists of a start/stop bit, data bits, and an optional parity bit. In the idle state, the line is held at high or one. The start bit indicates when data is coming, it is a transition from an idle high state to a low state which is quickly followed by the data bits. After the data bits are finished, the stop bit indicates the end of the data. It is a transition back to the idle state of remaining in the high state for an additional bit. The data bits can be between 5 to 9 bits, more commonly used are 7 to 8 bits. Data is typically sent with the least significant bit (LSB) first. A UART frame can also consist of a parity bit, which can be used for error detection. The parity bit is inserted between the end of the data bit and the stop bit. There can be even parity or odd parity, in even parity the number of 1's must be even, in odd parity the number of 1's must be odd. The parity bit can only detect a single flipped bit. Although UART was widely used, its popularity is decreasing and is being replaced by protocols like SPI and I2C which have higher speed and throughput.[13]

The inter-integrated protocol commonly called I2C is used primarily for short distance data communications. I2C is a synchronous master-slave protocol in which both master and slave and send and receive data. It operates in half-duplex mode and can run at different speeds. The master is connected to one or more slave nodes via two shared lines: serial data(SDA) and serial clock (SCL). The 2 lines are each connected to a voltage by a pull-up register. In an I2C frame, communication begins with a start condition followed by the address it wishes to read from or write data to, the slave acknowledges and then the data is transmitted and acknowledged, the data is terminated by a stop condition. The idle state in both SDA and SCL is high, the start condition occurs when a node pulls SDA low and then pulls SCL low in that order; in doing so the node becomes the master and prevents other nodes from using the bus at the same time. Each I2C node on a bus must have a unique, fixed address that is seven-bit long and is the most significant bit first (MSB). SDA does not change between the clock rising edge and the clock falling edge, during data transmission, SDA only transitions while SCL is low; an SDA transition when SCL is high indicates a start or stop condition. Following the slave address is the read and write (R/W) bit, if it is a zero it indicates that the master wants to write data to the slave, and if it is one it signifies that the master wants to read data from the slave. The acknowledge (ACK) bit is sent by the receiver each time a byte of data is received. Zero is an ACK and one is a NACK, a negative acknowledgment. Every slave address or data byte is followed by an ACK bit to confirm receipt of data. The data byte contains the actual information being transferred between master and slave. It is always 8 bits long with the most significant bit first, always followed by an acknowledgment bit. The stop condition applies when first SCL returns and remains high and then, SDA returns and remains high. The pull-up resistors used have a specific purpose that allows the flexibility to limit or increase the bus speed and time needed to pull up to the line. A higher resistance increases the time needed to pull up the line and limits the bus speed. Therefore, lower resistance values allow for faster communication by decreasing the pull-up time at the cost power. There are many modes I2C can be set at and their respective speeds[12]

Table 13. I2C Modes

I2C Mode	Speed
Standard Mode	100 kbps
Fast Mode	400 kbps
Fast Mode plus	1 Mbps
High Speed Mode	3.4 Mbps
Ultra Fast Mode	5 Mbps

High-speed modes are backward compatible with lower speeds. Ultra-fast mode is unidirectional meaning writes only.

SPI, also known as Serial Peripheral Interface, is a four-wire serial interface with speed improvements over other serial data protocols such as UART and I2C. Its most commonly used uses include sensors, displays, ADC, game controllers, and more. SPI is a master-slave protocol with a single master and one or more slaves connected by 4 wires: Chip Select (CS), Synchronous Clock (SCLK), Master Out Slave In (MOSI), Master Out Slave In (MISO). The chip select chooses the communication target, the SLCK provides synchronization and timing between slaves and master, the MOSI is data transmitted by the master and finally, MISO is data received by the master. A typical communication would start with the master pulling the CS line low to indicate to the slave that data is incoming and then start the clock. The MOSI line is used to send bits to the slave, and if the slave has bits to send back to the master it will do so via the MISO line. When communication is complete CS returns to its idle state of high. Using chip select is a simplified way to address targets or slaves, unlike I2C which uses addresses. Slaves do not require their own clocks, even when they are transmitting data. Clock speeds are in the MHz range which is faster than UART or I2C. the clock indicates what data should be sampled which can be either the rising or falling edge. Data is transferred from the master to one or more slaves using the MOSI line, data is usually 8 bits which can be the least or most significant bit first. On the other hand, MISO is used to send data from one or a slave to the master. Some devices do not include a MISO line; for example, displays only need to receive data from the master. Multiple slaves are configured by the master having separate CS lines to address each slave. Another mode of addressing multiple slaves is called Daisy Chain which eliminates a separate CS line for each slave. In a daisy chain configuration, the CS and SLCK line is shared among all slaves. However, MOSI data is sent to the first slave and then passed along to the next slave using the MISO line from the first slave to connect to the MOSI from the next slave, this process can be repeated depending on how many slaves. To send data from the slave to the master the data will go down the chain and be sent back to the master by using the MISO line from the last slave in the chain.[14]

The primary component driving the wireless communication for the variety of the laser tag must be chosen with several requirements in mind. Using IR and Bluetooth communication, we can achieve different functionalities for the game to function. For tagging, we can use IR communication. Each laser gun emits an IR signal when the trigger is pulled. The vest worn by the players has IR receivers, when a player is hit, the receivers on their vest pick up the IR signal from the gun. Each vest could also be equipped with an Arduino and a Bluetooth module, when a player is hit, the Arduino sends a signal via the Bluetooth module to a central scoring system. The scoring system, equipped with the master Bluetooth module, receives these signals and updates the scores accordingly. This setup allows for real-time scoring updates which will be displayed on each gun giving each player feedback to enhance the gameplay experience.

Table 14. Wireless Connections MCU

Protocol	UART	I2C	SPI
Communication Type	Asynchronous	Synchronous	Synchronous
Number of Wires	2 (TX, RX)	2 (SDA, SCL)	4 (MISO, MOSI, SCK, SS)
Data Transmission	Full-duplex	Half-duplex	Full-duplex
Speed	5 Mbps	Up to 3.4 Mbps	Up to 60 Mbps
Number of Devices	Point-to-point	Multiple, with unique addresses	Multiple, with individual chip select
Use Cases	Long distance, low speed data transfer	Short distance, low-speed data transfer between ICs	Short distance, high speed data transfer between ICs

Infrared communication is common, easy to use, and inexpensive for wireless communication. It is a cost-effective way to send over a few bits of data wirelessly. Many remote controls use this technology. Infrared LEDs produce light that is not visible to the human eye, it operates at a wavelength of about 950 nanometers. Many other sources emit infrared waves such as the sun, which presents a difficulty when communicating in daylight. The simplest way to transmit information is a binary of 1 when the trigger is pulled, then the receiver will detect such information and store it. Additionally, one option is to use the OpenLaterTag IR protocol, where there is a piece of detailed information on the packet that should be shooting in order for our game to function. The packet is used for game moderation and basic player settings. It contains 22 bits with the rightmost binary number used to identify which type of packer (0 for shot packet). The next 1-7 bits are used for the first part of the player ID, the 8-9 bits can specify teams, the 10-13 bits are used for damage, and lastly, 14 to 21 bits are used for the second part of the user ID. Furthermore, this can be customized to our laser tag system to complete the different game modes and settings we plan to implement.[7]

The Bluetooth modules use an SPP (Serial Port Protocol) for serial communication, creating a Bluetooth connection between two devices is a multi-step process with states such as inquiry, paging, and connection. The main function of inquiry is for the Bluetooth master to find all the other Bluetooth slaves in the system that are in range. The master will send out an inquiry request message and any device listening will respond by sending back its address, name, and other pieces of information. The paging state consists of forming a connection between the Bluetooth devices. For this to be possible each device must know the address of the other devices which was obtained in the inquiry phase. Upon the completion of the paging state, the device enters the connection state. From there there are a variety of modes it can be configured to function according to our needs. There are the active mode, the sniff mode, the hold mode, and the park mode. For the use of the laser tag system, the active mode is the most suitable since this is a mode where it is regularly connected, transmitting and receiving information. The other mode that can be useful is the low-power mode where the devices are only transmitting and receiving based on a set interval.

A Bluetooth module can communicate with a wide variety of devices, including smartphones and computers. This is a great option if we want a central system to monitor everything happening during the game. A very popular choice that is well-used along with the Arduino microcontrollers is the HC-05 Bluetooth module. It is used for many applications like game controllers, wireless headsets, and many more. It has a range of up to 10 meters which varies depending on the location and conditions. It communicates to the microcontroller via UART making it easy to implement and communicate.

Wi-Fi can be used for communication between the laser tag guns and a central system. This can be particularly useful in large arenas where Bluetooth's range might be insufficient. Wi-Fi has a standard range of up to 100 meters, which can cover a large area. The central system can be connected to a Wi-Fi network, and each gun can also be equipped with a Wi-Fi module, such as the ESP8266, which is compatible with Arduino. When a player is hit, the gun sends a signal to the central system over the Wi-Fi network, updating the scores in real-time. The ES8266 wifi is a system on a chip (SOC) with an integrated TCP/IP protocol stack that can give any microcontroller access to a chosen

Wifi network. It's capable of hosting a Wi-Fi network, making it a viable choice for real-time communication in applications such as laser tag. This SoC can provide any microcontroller with access to a chosen Wi-Fi network, enabling real-time score updates in a laser tag game.

Wi-Fi communication offers several advantages. Firstly, it provides a larger range of up to 100 meters, making it suitable for large arenas where Bluetooth's range might be insufficient. Secondly, Wi-Fi modules like the ESP8266 are compatible with popular microcontroller platforms like Arduino, making them easy to integrate into various applications. Thirdly, Wi-Fi allows for real-time communication, which is crucial for applications like laser tag that require immediate feedback. However, Wi-Fi communication also has its drawbacks. One of the main disadvantages is power consumption. Wi-Fi modules consume more power compared to other wireless communication methods like Bluetooth Low Energy (BLE). This could be a concern for battery-powered devices like laser tag guns. Another potential issue is interference. Wi-Fi operates in the 2.4 GHz or 5 GHz bands, which are shared by many other devices and can lead to signal interference. In comparison, Bluetooth, specifically BLE, is designed for short-range communication and consumes less power than Wi-Fi. It's ideal for applications that require low power consumption and short to medium-range communication. However, its range is typically less than that of Wi-Fi, making it less suitable for large arenas.

Table 15. Wireless Connection Non-MCU

	IR	Bluetooth	Wi-Fi
Communication Type	Infrared light pulses	Radio waves	Radio waves
Range	Up to 5 meters	Up to 100 meters	Up to 100 meters
Data Transmission	Up to 15 Mbps	1-3 Mbps	Up to 600 Mbps
Power Consumption	20 mA	30-40 mA	240-250 mA
Interference	Low (line-of-sight required)	Moderate (2.4 GHz band shared with other devices)	High (2.4 GHz or 5 GHz bands shared with other devices)
Use Cases	Suitable for close-range, line-of-sight communication between guns and sensors	Suitable for medium-range communication between guns and a central system	Suitable for long range communication between guns and a central system, especially in large arenas

In conclusion, while Wi-Fi communication offers advantages such as a larger range and real-time communication, it also has drawbacks like higher power consumption and potential for interference. The choice between Wi-Fi and other communication methods like Bluetooth would depend on the specific requirements of the application. For a laser tag system in a large arena, the benefits of using Wi-Fi could outweigh the drawbacks. However, for smaller arenas or power-sensitive applications, other communication methods like BLE might be more suitable.

4.0 Standards and Design Constraints

Standards and constraints are very important factors that need to be analyzed and researched as they can represent the safety of the user when using the products. Without understanding the different standards and constraints that would be part of this project, then we would not be able to succeed in the public market and also pass any sort of tests for safety when submitting our project to be published. For the standards of this project, there are many different corporations or organizations that developed a very good but basic baseline for the different standards for each component in our project. Also, the different constraints that we are going to experience when making the project are also important to understand since they can affect the overall design of our project.

4.1 Standards

Standards in engineering and development are published documents that establish technical specifications and procedures to maximize the reliability of the material, products, and services. They are used consistently as rules, guidelines, or definitions of characteristics to ensure products and services are fit for their purpose. They are a common language that engineers abide by to create a better user experience. Standards can be thought of as agreed-upon norms used by people, the industry, and the government that outlines the best way to complete a task. Standards are typically published by organizations, committees, or government departments. Among a variety of groups, some include international standards like the Institute of Electrical and Electronics Engineers (IEEE), the International Federation of Organic Agriculture Movements (IFOAM), and the National Electrical Manufacturers Association (NEMA). There are also regional standards organizations like the European Committee for Electrotechnical Standardization (CENELEC), and the Arab Industrial Development and Mining Organization (AIDMO). There are also national standards in which each country has their standards they uphold.

Standards are an important part of the design process of every engineering project. Recognizing and identifying the related and necessary standards is a skill that takes research and knowledge of the product and market you are trying to design. Many standards are created for safety purposes for the user or manufacturer of a product or device. Standards are also created for portability, intercommunication between different devices, and software-related.

In this section, we will go over the necessary standards that apply to our Laser Tag project. We will go over the safety issues concerning the batteries, lasers, and many other electronic components in our design. As engineers and designers, we aim to adhere to the necessary standards that promote safety and ease of use.

4.1.1 IEEE

The Institute of Electrical and Electronics Engineers Standards Association (IEEE SA) is an organization within IEEE that develops global standards that apply to a wide range of industries. These industries include power and energy, consumer technology, the Internet of Things, information technology and robotics, nanotechnology, transportation, and many more. These standards are developed through a consensus process and are designed to help engineers, developers, and industries maximize the reliability, efficiency, and interoperability of products and systems1. They provide a stable foundation that enables industries to develop and thrive. For example, the IEEE Guide for Developing System Requirements Specifications provides guidance for the development of a set of requirements, known as the System Requirements Specification (SyRS), that will satisfy an expressed need. Developing a SyRS includes the identification, organization, presentation, and modification of the requirements. When developing a wireless laser tag system this guide can be very instrumental and important to ensure that all necessary requirements are identified and correctly organized. A system Requirement Specification (SysRS) is a document that communicates the requirements of the customer to the technical community which will specify and build the system. The list of requirements and how its represented acts as a bridge that connects the two groups of both the consumer and technical community for them both to have a mutual understanding. There is a distinguishable difference between the system requirement, what the system does, and the process requirement, how the system is constructed.[29]

Some of the key points from this document include:

- **Identification**: Identify all the necessary components of the wireless laser tag system. This could include laser tag guns, vests, charging stations, and any software needed to run the games.
- **Organization**: Organize these components into categories based on their function. For example, hardware (guns, vests) and software (game control systems).
- **Presentation**: Present these requirements in a clear and understandable manner. This could be in the form of tables or diagrams that show how the different components interact with each other.
- **Modification**: As the design process progresses, requirements may need to be modified or updated. This could be due to changes in technology, user feedback, or other factors.

4.1.2 Laser Safety Standards

Laser safety is a crucial aspect of working with lasers due to their unique properties and potential hazards. Lasers are a part of the electromagnetic spectrum, which includes X-rays, visible light, and microwaves. When electromagnetic radiation falls within the range visible to the human eye (380-780 nm), it’s known as visible light. If all wavelengths in this range are emitted at once, we perceive it as white light. When white light interacts with an optically dispersive element like a prism, it refracts to reveal the visible spectrum, transitioning from violet to red as the wavelength increases. Even at lower power levels, lasers can cause irreversible eye damage from a single accidental exposure, depending on the wavelength, output, and exposure duration. Laser safety is also important for preventing equipment damage. A key factor in assessing damage potential is irradiance, which is the power per area (expressed in watt/cm2). Lasers have unique properties that distinguish them from natural light sources:[20]

- **Coherent**: They have a fixed relation to time and space.

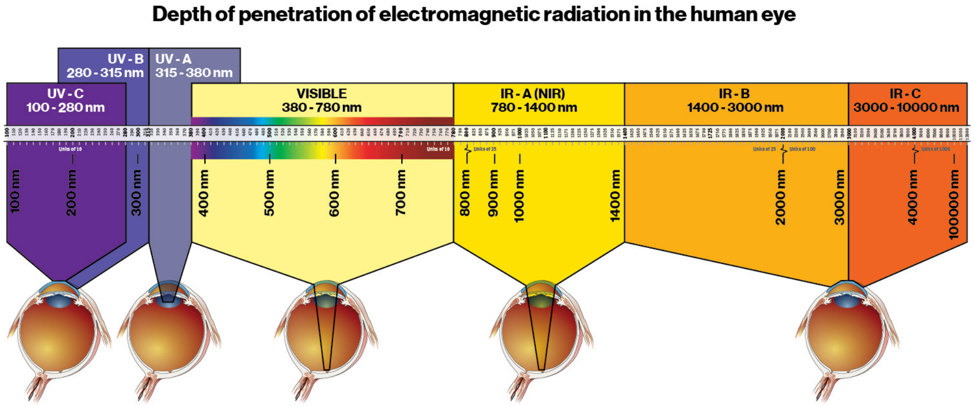
- **Monochromatic**: They consist of the same wavelength.
- **Collimated**: They can travel long distances as a nearly parallel beam.
- **Independent Power or Energy**: The power or energy that impacts an area, such as the eye, is independent of the distance to the radiation source.

Wavelengths between visible light (380-780 nm) and near-infrared wavelengths (700-1400 nm) are focused by a lens to a spot size—a factor of ten smaller than normal incoherent light. While a standard light bulb creates an image on the retina of approximately 100 µm, laser light can be reduced to a spot of just a few micrometers (~ 10 µm) in diameter. This means the light quantity that hits the eye is concentrated on a much smaller spot. Due to the refractive and focusing properties of the eye, the retinal irradiance is a factor of 100,000. The power density (power per area or watts/cm2) resulting from this concentration could be sufficiently high to the point that any tissue in the focused area will be heated and rapidly destroyed. It is possible to lose your eyesight from a single laser pulse, since the fovea, which is responsible for sharp central vision and located on the retina, is the size of a few micrometers.

Infrared (IR) receivers and emitters typically operate within the infrared light spectrum, which ranges from 700 nanometers (nm) to 1 millimeter (mm). The devices that emit and detect IR are very simple. Specifically, the wavelength of light that such devices output is typically around 950 nanometers. IR emitters with a wavelength of 940 nm are the best match for IR receivers using carrier frequencies between 30 kHz and 56 kHz.

As for laser hazards, the Occupational Safety and Health Administration (OSHA) provides comprehensive guidelines. The most common cause of laser-induced tissue damage is thermal in nature, where the tissue proteins are denatured due to the temperature rise following absorption of laser energy. The human body is vulnerable to the output of certain lasers, and under certain circumstances, exposure can result in damage to the eye and skin. It is now widely accepted that the human eye is almost always more vulnerable to injury than human skin. OSHA also addresses non-beam hazards associated with the use of lasers. These can be life-threatening in some cases, such as electrocution, fire, and asphyxiation. Laser hazards are addressed in specific OSHA standards for general industry and construction.[18]

Figure 5. Eye Safety



4.1.3 Wi-Fi Standards

Wi-Fi is a wireless local area network(WLAN) technology that enables digital devices within a certain area to communicate via radio waves. The Wi-Fi Alliance developed a naming system ("Wi-Fi #") to help the public distinguish between different IEEE 802.11 implementations:[28]

- **IEEE 802.11™**: This is the original 2.4 GHz Wi-Fi standard from 1997, which is still in use today. It and its subsequent amendments form the foundation for Wi-Fi wireless networks and are the most commonly used wireless computer networking protocols globally.
- **IEEE 802.11b™ (Wi-Fi 1)**: Launched in 1999 alongside Apple's announcement, Wi-Fi 1 also operates at 2.4 GHz. To achieve higher data rates and reduce interference from sources like microwave ovens, cordless phones, and baby monitors, it uses modulation schemes known as direct-sequence spread spectrum/complementary code keying (DSSS/CCK). Wi-Fi 1 supports wireless communications at distances of approximately 38m indoors and 140m outdoors.
- **IEEE 802.11a™ (Wi-Fi 2)**: Introduced in 1999 as the successor to IEEE 802.11b, Wi-Fi 2 was the first Wi-Fi specification to use a multi-carrier modulation scheme (OFDM) to support high data rates, unlike Wi-Fi 1's single-carrier design. It operates at 5 GHz, and its 20 MHz bandwidth supports multiple data rates.
- **IEEE 802.11g™ (Wi-Fi 3)**: Launched in 2003, Wi-Fi 3 allows for faster data rates of up to 54 Mbit/s in the same 2.4 GHz frequency band as IEEE 802.11b, thanks to an OFDM multi-carrier modulation scheme and other enhancements. This was attractive to mass-market users, as 2.4 GHz devices were cheaper than 5 GHz devices.
- **IEEE 802.11n™ (Wi-Fi 4)**: Introduced in 2009, Wi-Fi 4 supports the 2.4 GHz and 5GHz frequency bands, with data rates up to 600 Mbit/s, multiple channels within each frequency band, and other features. The data throughputs of IEEE 802.11n enabled the replacement of wired networks with WLAN networks, a significant feature that opened up new use cases and reduced operational costs for end users and IT organizations.

- **IEEE 802.11ac™ (Wi-Fi 5)**: Introduced in 2013, Wi-Fi 5 supports data rates up to 3.5 Gbit/s, with greater bandwidth, additional channels, improved modulation, and other features. It was the first Wi-Fi standard to enable the use of multiple input/multiple output (MIMO) technology, allowing multiple antennas to be used on both sending and receiving devices to reduce errors and increase speed.
- **IEE 802.11ax (Wi-Fi 6)**: it is the most recent standard in the list, published in 2021. Although its theoretical data rate is 9.5 Gbits/s, this standard priority is not about boosting Wi-Fi speed necessarily, instead, it addresses the fact that Wi-Fi usage is pervasive and network performance can be degraded in areas of dense Wi-Fi traffic such as public transportation, sport stadium, concert halls and even into our home where more and more devices use Wi-Fi to communicate simultaneously.

The ESP32 chips we are using adhere to the IEEE 802.11 Wi-Fi standards, specifically, it supports the 802.11 b/g/n standards in the 2.4 GHz band reaching speeds up to 150 Mbps. This adherence to the Wi-Fi standards ensures that the ESP32 can communicate effectively with other devices on the same network. While the ESP32 does not currently support newer standards such as the 802.11ax or Wi-Fi 6, its compatibility with the 802.11 b/g/n standard ensures that it can still communicate successfully with a wide range of devices.

4.1.4 Battery Standards

Our wireless laser tag system is upheld by batteries that keep components running wirelessly. The primary standards that apply to our project are set by the International Electrotechnical Commission (IEC).

IEC 60086-1:2021 is intended to standardize primary batteries with respect to dimensions, nomenclature, terminal configurations, markings, test methods, typical performance, safety, and environmental aspects3. This document specifies requirements for primary cells and batteries. The standard covers various aspects of battery design, including battery dimensions, terminals, classification (electrochemical system), designation, and marking. It also talks about interchangeability, the object of this part of IEC 60086 is to benefit primary battery users, device designers, and battery manufacturers by ensuring that batteries from different manufacturers are interchangeable according to standard form, fit, and function. The standard also specifies the discharge performance, dimensional stability, leakage, open-circuit voltage limits, service output, and safety of the batteries. It also specifies standard test methods for testing primary cells and batteries. IEC 60086 consists of several parts, including general guidelines (Part 1), physical and electrical specifications (Part 2), watch batteries (Part 3), safety of lithium batteries (Part 4), and safety of batteries with aqueous electrolyte (Part 5).[27]

We plan on using AAA rechargeable batteries in order to power our system. Rechargeable AAA batteries have the same standardized size and nomenclature as non-rechargeable AAA batteries under IEC 600861. This ensures that rechargeable AAA batteries from different manufacturers will fit into the same battery compartments and are referred to by the same name. Rechargeable AAA batteries must be safe to use and dispose of, according to the safety and environmental guidelines in IEC 600862. The IEC 60086 provides guidance on the proper scientific protocols for testing the environmental performance of batteries. By following the IEC 60086 standard we make sure that our batteries are cheap, have great performance, and can be easily replaced.

- **Dimensions and Nomenclature**: Rechargeable AAA batteries have the same standardized size and nomenclature as non-rechargeable AAA batteries under IEC 60086. This ensures that rechargeable AAA batteries from different manufacturers will fit into the same battery compartments and are referred to by the same name.
- **Terminal Configurations**: The standard also specifies the terminal configurations for rechargeable AAA batteries. This means that the positive and negative terminals are in the same location for all AAA batteries, regardless of whether they are rechargeable or not.
- **Markings**: Rechargeable AAA batteries are required to have certain markings, such as the manufacturer’s name, the battery type, and the polarity. These markings help users to correctly install the batteries.

- **Test Methods**: Rechargeable AAA batteries are tested according to the methods specified in IEC 60086. These tests ensure that the batteries perform as expected under various conditions.
- **Performance**: The performance of rechargeable AAA batteries, including their capacity and discharge characteristics, must meet the requirements of IEC 60086.
- **Safety and Environmental Aspects**: Rechargeable AAA batteries must be safe to use and dispose of, according to the safety and environmental guidelines in IEC 600862. The IEC 60086-6:2020 provides guidance on the proper scientific protocols for testing the environmental performance of batteries.

4.2 Design Constraints

Design Constraints are extremely important in project development and can be the main factors in a project's success. Every project starts with just an idea but to progress into a working design or product it must go through many steps such as research, prototyping, testing, and most importantly design constraints. This step in project development is extremely important because this is where a design is decided to be a useful product or a waste of time, money, and effort. This is because these design constraints describe how useful this design is over many important topics and the limitations that must be achieved in order for the design to become a successful product.

In the ABET lecture and slides given to us throughout the semester, we can learn a lot about these constraints and their uses for our design. Since we are building a senior design project and not an actual product on the market these design constraints will slightly differ from other mass-produced products. These ABET design constraints that are given to us in our senior design class include economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. We decided that these constraints cover almost every aspect of what our design must include in order to meet our requirements. The only thing missing that we decided was important for our design was time constraints due to how important that is for our design and how that can affect its outcome. Overall these constraints that we selected should give us a good well rounded design.

Each and every one of these constraints are extraordinarily essential to a project and make or break its success in the real world. This is due to how important each of these constraints is and how if a project does not meet a minimum requirement for any constraint it will immediately fail. For example, if a design is too expensive to make it will not be sold on the market because nobody will pay for it this is a perfect example of a failed economic constraint. This shows the importance of design constraints and how they influence a project. Now that we understand just how important design constraints are and which ones we choose we need to understand how they are specifically quantified and evaluated by engineers.[15]

4.2.1 Time Constraints

Time constraints are imperative in our design due to the impeding time requirements that exist in our class that influence our project's outcome. Although this constraint was not given to us in our ABET lectures we decided that due to its importance, it must be included in our design constraints section. Our project has many instances of time constraints applied to it and each one is imperative to our project. Although there are other time constraints that apply to our project the main ones are deadlines that we must finish parts of our project by.
These deadlines or due dates for certain parts of our project are set by the professors and advisors in order to make sure that we are accomplishing our designated tasks at an ample rate to keep us on track to finish in time. These deadlines revolve around the school semester which is sixteen weeks long and given that we have two semesters to finish our project we are given around thirty-two school weeks total. These deadlines for certain parts of our project are super important if they didn't exist the likelihood of students trying to finish an entire project in the last few weeks and failing would drastically increase.

Our first-time constraint that we must adhere to is in senior design one where at the end of the semester we are required to present a one-hundred-and-twenty-page paper that describes our project and its entirety to peer reviewers. This paper is split into sections that must be turned in one at a time including a ten-page and a sixty-page paper. With this comes the hard part at the end of the semester we must create a working demo of our project. This means that as we are writing about our project and the things we must do to make it functional we must also be building it at the same time. This can be quite the time constraint given the short amount of time that we are given to complete tasks that may take large amounts of time.

Our second-time constraint is in senior design two where we must finish our design in its entirety making sure that it's fully functional and operational and present this to our peer reviewers to show what we have built. This time constraint is slightly different than the one in senior design for many reasons. One issue that this time constraint could give us is unlike in senior design one we must fully complete our project which means if we run into problems in our design we must fully fix them before the deadline. This makes our time constraint very complicated and could lead to major errors down the road if not planned correctly.

This time constraint of deadlines for senior design one and two is extremely important to stay ahead of and our team has tactics that we use to make sure we meet deadlines and don't fall behind. One way that our team has been staying ahead of these time constraints is by making soft deadlines for certain parts of our project. This means that we aim to finish parts of our project by certain times before it's due to give us some leeway to finish in time. Another way to make sure everything is getting done is to stay in close contact and hold each other accountable for the work that that person must do. These different types of solutions that we apply help us control the time constraints at hand and make sure we are getting things done.

Another time constraint that is very impactful for our project is shipping times. Since we had very little time to build our demo prototype for senior design shipping was a major factor in how much time we had to build our demo and what parts to order. For example, we changed which parts we were going to order due to one having a faster shipping time compared to other options. We also have issues with one of our parts coming in on time due to it taking a long time to ship from China. Although shipping is a major concern for senior design one because we need to order things at such short notice it shouldn't be such a big deal for senior design two. This is because since our group is taking senior design two in the fall we get around three months between the classes which gives us plenty of time to order the parts we need for our project.

There are many other minor time constraints that are factors to our design and can affect the overall flow of our project. It's best to be aware of these time constraints and work as hard as we can to minimize the negative effect it could have on our project. Overall time constraints are a huge part of our project and we must take precautions to make sure we keep ahead of these constraints in order to have a successful project.

4.2.2 Economic Constraints

Economic constraints are arguably the biggest factor in every project and product that exists and is especially prevalent in our design. When creating any design or product and you think about the constraints that could be an issue, economics should be one of the first that comes to mind. This is because most products are made to be economically advantageous so that they can make the most amount of money possible. Economic constraints are the main reason every single product that exists is made this is because someone had a good idea and decided to sell it as a product. Bigger companies with more money have the ability to design more products and with good economic advisors, they can make sure to have solid economic constraints to ensure that every product is successful.

This doesn't just affect the creation of new designs and products but also how these products are produced, manufactured, and sold on the market. Companies with good economic values and decisions are able to make an ample amount of money off of each product that is sold to sustain that product's design creation and manufacturing of that product. The more money that they can acquire from a product the more of that product they can produce to receive more money until they are big enough to mass produce the product. This just shows how important finance is in designing and that every single product has many economic constraints making it impossible to avoid due to how important it is.

Not only are economic constraints important in our design but more so it's immensely different from economic constraints in other related products due to the circumstances of our product. In most products made by companies, the main economic constraints revolve around is this product able to be sold in ample quantities at a price that we can produce to gain a monetary profit. However, our project isn't going to be sold on the market so for us when designing and realizing our economic constraints we don't have that aspect of trying to produce a profit that most other products have. Another difference is that our project is going to be completely self-funded and paid for by our team and split among its members.

The main economic constraint that will be apparent in our project is that it is completely self-funded. This entails that each part that we purchase to complete our design will come straight out of our own pockets. This will greatly influence the budget and scope of the project when compared to designs that have significant amounts of funding behind them. Since we have to purchase everything ourselves we will be attempting to make the budget as minimal as we physically can while still spending enough to make a fully functional and efficient design. There are many ways we can achieve this to make a great project at an affordable price.

One of the best ways to save money is to reuse parts that we already have when possible this can save us from buying new parts we don't need. In our project, we were able to reuse many parts that we already had that we have gotten from many sources such as previous classes, projects that we have done, and random stuff. For example, in a previous class junior design, we were all required to buy liquid crystal LCDs, jumper wires, breadboards, and potentiometer and we managed to keep most of ours. In previous projects that we have done, we have been able to save parts that will be of use for our projects such as LEDs, buttons, and microcontrollers. Random stuff has also greatly helped us we managed to use an old battery-powered nerf gun to hold our demo which has saved us a great amount of money compared to building one ourselves. Although these examples of things that we have reused are mainly helpful for testing and creating our first prototype and may not be used in our final design they have still saved our team significant amounts of money.

Another way we can save money when building our project is by using the resources available to us as senior design students at the University of Central Florida. Our school provides an amazing senior design lab that is filled with all sorts of useful tools and professional advice from Dr. Weeks who is usually in the lab. These tools have come in handy for us when building our prototype as we have already spent multiple hours in the lab using its variety of equipment. When designing our first prototype we used many of the tools in the lab such as using the provided multimeters, the soldering area built with everything you could need to solder things together, and all types of tools like wire cutters and strippers and every type of screwdriver or basic tools you could need. This lab has so many more useful tools that we have yet to use due to not needing them while building the first prototype but will most definitely come in handy even more so when building our final design for our project.

4.2.3 Manufactory and Sustainability Constraints

Manufactory and Sustainability constraints are super important in the world of project design and can have a huge impact on the prosperity of a product. This is because of how influential it is when paired with economic and time constraints. To make sure a product is successful it must be able to be manufactured in ample time at a rate able to be sold for profit. This won't matter if the product you are selling isn't sustainable as nobody will buy it. ALthough these are both huge in the world of project design when it comes to our senior design project manufactory isn't very important however sustainability still is imperative.

Manufactory constraints are a huge issue in product design for larger companies due to the standard that they hold when mass-producing products. Our senior design project however is most definitely not being mass-produced so this constraint is very much less of an issue for us. Although we don't mass produce we still have to make two phasors and vests so we do have to produce more than one so we do have a small manufactory process. This however since it's such a small scale is done by hand and not a machine so we can just copy the steps used to make one on the other.

Sustainability however is a huge factor in our project as making our design very sustainable and reliable is exceptionally significant to its success. This is because of the high standard we must have when it comes to demoing the product and its reliability. If we had a project that wasn't reliable and broke before the demo we would fail and the project would be a complete flop. This can be a major issue in our design due to the abnormal stress that a laser tag project may incur such as shaking, falling, and getting hit which can increase the chances of our design breaking. In order to make sure this does not happen we must make our design very sturdy to take external stress and warn users to try to keep stress on the project from happening.

4.2.4 Health and Safety Constraints

Health and safety are extremely important when building our project because the last thing we would want is to harm ourselves or others while trying to create a safe fun to play game. There are lots of techniques to make sure that the safety of users remains intact that we will take. Most of these safety techniques are going to be precautions that we will take prior to avoid any sort of issues. If any issues were to happen we must also prepare for these as best we can to make sure no further damage is done. Overall health and safety should not be such a huge problem if the design is used correctly and the users using it follow instructions that are given to them and most importantly use some common sense.

The best way to make sure to cover all our bases when it comes to health and safety constraints is to take precautions. One of the main precautions we can take is to watch the exposure of light in our eyes when building and using the phasor. Although infrared light is harmless if you have long exposure it can cause damage to your eyes to solve this we can make sure we use glasses or try not to stare directly into an infrared light for a long period of time. When testing we also use a red LED to see the optics as infrared is invisible which makes it easier to test this we must be careful to not stare into the laser that the LED produces. Other safety concerns we have can involve electrical work as working with electrical components can lead to some safety concerns such as things blowing up if used incorrectly. To make sure we don't run into these issues we can use the knowledge we have from research and previous classes on how electrical components work before testing them.

Other safety issues that may occur don't involve the design of the project but actually compromise primarily on the usability of the project. These can be especially important because as the people building the project, we understand how it functions but if a user is trying the project for the first time they may run into safety issues. To make sure we avoid this we can follow basic laser tag rules such as no running and make some more rules as we test the project further.

If for some reason a safety issue still does occur we must be able to act quickly to stop further damage. Although proper safety precautions will be taken accidents do happen and you never know what can happen at any moment. If a situation like this does occur we will try to act as quickly as possible and if the emergency is severe we can always call the ambulance or other trained professionals to assist us.

4.2.5 Environmental Constraints

Environmental constraints are super important when designing a product. Most Environmental constraints that our project will face revolve around hazardous substances and making sure to keep proper etiquette when it comes to the parts you use and how to take care of them, store them, and dispose of them. To do this we have to make sure we are avoiding hazardous materials that can negatively impact the environment. We need to also make sure to keep track of our items and make sure that we use them properly.

To make sure that we are choosing parts that are not negatively affecting the environment with proper use we will make sure to use RoHS-approved products. These products are described by the Restriction of Hazardous Substances directive restricts the use of the following ten substances Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls, Polybrominated diphenyl ether, Bis(2-ethylhexyl) phthalate, Butyl benzyl phthalate, Dibutyl phthalate, and Diisobutyl phthalate. Making sure to buy products that avoid these materials in more than very small quantities can greatly improve our project's environmental impact.

To make sure that we are using the parts correctly we need to have some precautions when it comes to using, taking care, storing, and disposing of them properly. To do this we can make sure to research each component and even more so ones like batteries and electrical components that could have a greater environmental impact. Another great option is to use recycling when it comes to disposing of parts when possible. Although most of the parts if used properly should not have any environmental impact we can never be too sure and it's always better to play it safe.

4.2.6 Social, Political, and Ethical Constraints

For our project, a huge aspect of it is how it will affect people who come into contact with it and this is where social, political, and ethical constraints come into play. While designing our project we have to think about these constraints although some are more important than others they all must be taken into consideration. Social constraints are a huge part of our project as we are designing a game that is meant to be played in a social setting. Political constraints are definitely less influential on our project as we don't intend to make a political scene but we must always be prepared. Ethical constraints that this project can have will be mainly focused on our team and the ethics that we must adhere to while designing this project.

Social constraints are a large part of the project and will affect the outcome of the popularity of our product. Social constraints are really important for big businesses when designing products because how the community you release it to reacts to this product will greatly influence its success on the market. This is no different for us as senior design students. We must keep a positive social presence in order for our design to have a positive review which will influence the accomplishments we plan to achieve. To do this we intend to make the game very user-friendly in order for the people playing our game to have positive feedback and reviews of it.

Political constraints are not a giant problem that we foresee in our project but nevertheless, anything is possible and we must always be prepared. One of the only ways our product could be affected politically is around the gun design and its safety measures. To make sure that we fully avoid this we are taking many precautions to ensure safety for our players.

Ethical constraints can exist in a project and usually can occur within the design group. Examples of this could be people from the group not treating others with the respect they deserve or breaking some of the ethical rules that exist at the University of Central Florida. To make sure we don't run into any of these issues we plan to make sure every member gets along well and if that fails to talk to our superiors to resolve the issue with the least amount of problems possible. Another ethical constraint is cheating which also exists within groups to make sure to avoid this we will make sure to read the guidelines of what we are and aren't allowed to do to make sure to follow the guidelines provided to us and ask questions if needed.

5.0 Artificial Intelligence

Artificial Intelligence (AI) is, simply put, a part of computer science that has to do with creating systems that mimic the mechanisms of human intelligence as well as performing tasks that would normally require a human being. Some examples of what AI can do are as follows: object detection, speech recognition, translation, decision-making, learning from experience, and even strategic planning. Because AI involves the simulation of the human mind, it is in a unique multidisciplinary field that uses elements from math, computer science, psychology, any studies relating to the human brain, and even economics and much more. There are a few key aspects of AI that are important and leading-edge technologies: machine learning, deep learning, natural language processing (NLP), robotics, and computer vision, to name a few.

So, the question is, if AI can perform tasks that usually require human intelligence, how can we use that to help us? First, let's take a deeper look at what kind of tasks AI can currently perform starting with machine learning. Machine learning is one of the most important advancements made in AI, which, in simple terms, allows an AI system to use data to make decisions and learn from it. Unlike regular programming, where everything a computer does needs to be hard-coded by a human being, machine learning allows a system to develop its own behaviors based on empirical data. Supervised learning is a major method of development for machine learning. Through this technique, an AI system can use a datasheet to analyze some given input with correctly labeled outputs and then form a general rule of mapping inputs to outputs. Unsupervised learning is similar but now the system is trying to learn patterns without the use of labeled data. The final technique we will talk about, reinforcement learning, is when an AI system learns how to optimize its actions through a trial-and-error reward system. How exactly does this benefit the user? This allows humans to simplify the decision-making process by just having to feed the data to a machine-learning AI, therefore improving efficiency and even accuracy. Through machine learning we can quickly analyze large amounts of data, predict outcomes, and make an informed decision, ultimately increasing workflow in many fields; including diagnoses in the medical field or predicting a financial outcome just to name a few.

Deep learning, which is a subset of machine learning, uses multi-layered neural networks to mimic a human brain. Multi-layered neural networks use input and output layers with multiple artificial neural networks in between; those middle layers are what do the data analysis to learn the complex patterns in the data to be able to model its own. Through this, the networks can make informed decisions on their own. AI capabilities such as speech recognition, natural language processing, and image recognition have all been steadily pushed forward with deep learning. What machine learning helps us with, deep learning does as well, but again deep learning does significantly enhance AI's ability to analyze auditory and visual data.

Another key aspect of AI is Natural Language Processing (NLP). What NLP enables machines to do is identify and interpret human language whether it is spoken or written. Things like translating a spoken language, responding to a human speaking to it, or even summarizing large amounts of text are all possible through NLP. AI assistants such as

Siri, ChatGPT, Google Assistant, etc. All utilize NLP to interact with users in a human-like manner. With NLP’s ability to allow computers to understand and interact with human language, we have greatly improved communication and accessibility through all languages and platforms. It is through this technology that user experience and information processing have been enhanced so much since the introduction of AI.

AI is not just limited to software; we can use AI for machines to help us perform tasks that humans may not be capable of or just as a more consistent and safe method. For example, the improvement of assembly lines through the power of AI, performing surgery, or even being able to drive a car with no human interaction. We have been able to improve efficiency, precision, and safety in many industries with robots and as we improve the technology, we will only have more areas to enhance.

The last key aspect of AI we will look at is computer vision. Basically, computer vision allows computers to interpret the world through visual data. The way this works is by feeding a machine vision system visual data, using an analog-to-digital converter, and then using digital signal processing. What we achieve by doing this is computer vision being able to get useful information from one image or video. This ability improves all walks of life such as security, and automated home monitoring in real-time with built-in threat protection. Medically speaking computer vision may be able to help detect any diseases early and accurately, therefore, benefiting the healthcare system. That and so many more situations in which such an ability can help.

5.1 Comparison of AI Platforms

Artificial Intelligence (Al) has evolved to change our very ways of life, revolutionizing how we use technology. The current leading platforms of AI that are changing the way we as humans perform daily tasks are OpenAl's ChatGPT, GitHub's Copilot, Google's TensorFlow, and IBM's Watson. Each platform has its distinct features and illustrates the versatility and transformative potential of Al technologies. ChatGPT, developed by OpenAl, is a flagship language processing Al that interacts in a question-and-answer manner. It can generate understandable and relevant fully formed responses based on prompts, making it a very useful tool for applications ranging from customer service bots to interactive learning aids. ChatGPT’s extraordinary ability to understand human input and to return a human-like output opens the door for more natural human interactions with machines, which in turn enhances the user experience. It has gotten to the point that at times it has gotten scary to how human AI can be. However, ChatGPT functions based on large language models which means that at times the AI can provide responses that are not fully correct or even biased; it is for these reasons that it is crucial that the user does their own research to make sure that the AIs response is fully accurate. Another innovative AI tool, GitHub's Copilot, helps software engineers by having code suggestions in real-time, it can even suggest entire functions. This tool, powered by a variant of the GPT model, actively reduces the amount of time spent by software engineers on any particular task which as a result increases productivity. While Copilot can dramatically speed up coding, especially for experienced programmers, the solutions it produces may not always work as the user intended or can be inefficient, which requires careful review by the user. On the other hand, Google's TensorFlow is an open-source library that makes calculations with data flow graphs much easier. TensorFlow plays a major part in developing machine learning models and has many uses in academic and industrial research. What makes TensorFlow such an ideal AI for building machine learning algorithms is its flexibility and scalability. However, there is a steep learning curve to overcome and complex data preparation to use AI to its fullest potential. IBM Watson, another Al-leading platform, offers Al-powered applications to help different fields make critical decisions. Watson's ability is to process and analyze large sets of data to provide meaningful insight that would normally take someone multiple hours to process. This ability can be essential for decision-making in healthcare, finance, and customer service. Watson's smooth and effortless integration into many businesses has greatly enhanced. Efficiency and accuracy since AI has helped companies to automate complex tasks. However, Watson's integration is not so easy for small businesses since Watson is costly and at times requires an extra framework. Collectively, all the AI platforms discussed show the type of impact they have had on all walks of life and how much can be improved in the future. Something that also must be considered is the challenges faced when utilizing AI such as inaccuracy, quality of code, bias, and complicated or expensive implementation. As time goes on, we can expect to see all issues diminishing while also opening the door for innovation and efficiency.

5.1.1 ChatGPT

ChatGPT is famously known not just by the intelligence community but also by the regular public. This is thanks to Chat's ability to produce an output almost indifferentiable from a human and being able to understand complex prompts. In any situation where natural language processing plays a role, ChatGPT is very beneficial. For example, ChatGPT can be used in a customer service setting to respond to callers all while providing contextually appropriate responses; this enhances the experience for users while also lowering the workload for employees. Similarly, within the field of education, ChatGPT can act as a tutor for students offering detailed explanations and useful information tailored to their questions.

Additionally, another application of ChatGPT is for creating content such as: generating articles, reports, or even creative pieces. This reduces time and effort for these examples, but productivity and motivation go down. An added benefit is the ability to expand one's content strategies which can help someone to run a business with as few extra employees as possible. Moreover, an obvious use case for ChatGPT is as a translator due to its proficiency in language.

When we are comparing ChatGPT to the other AI platforms Chat stands out that it involves the understanding and production of natural language. TensorFlow is more focused on machine learning tasks, Copilot is used in the programming process for developing code and Watson is great at analyzing data for businesses. ChatGPT's ability to interact with users in a way that feels natural and easy is one of the main contributors to its great success and what makes it stand out. In cases where interaction with humans is necessary ChatGPT exceeds, as well as in producing results in a human-like manner that can be easily used by any individual for their benefit in either learning or completing tedious tasks.

5.1.2 Copilot
GitHub Copilot, which is a collaboration between GitHub and OpenAI, has proven to be very useful in the programming world for its increase in efficiency and workflow. The ability of this advanced AI is the power of having real-time suggestions to implement into a programmer's code right in the code editor. This feature facilitates the development of coding for simpler tasks and allows the programmer more time to focus on the more difficult parts where Copilot cannot assist.

Copilot's main advantage is the boost of productivity through its simplification of simple tasks. Copilot’s benefits are more than just an accelerator though as the suggestions can also help new programmers learn a language quicker by showing common practices and uncommon APIs. It doesn’t matter which level of programming expertise you are at though since anyone can learn new methods and APIs through Copilot’s AI technology.

Copilot can differentiate itself from other AI platforms by focusing specifically on code generation. Unlike TensorFlow which is used for constructing and training machine learning models or Watson which focuses on huge data analysis mostly for enterprises, Copilot is excellent in aiding in coding tasks.

5.1.3 Others
Now let’s go into further detail talking about some of the other AIs starting with Google TensorFlow, mainly known for the development of other machine learning applications. TensorFlow allows developers for these complex AIs to be easily constructed and trained, largely due to it being an open-source library. The open-source library is needed to train any machine learning AI to be able to recognize imagery and speech, both in written and spoken form.

What differentiates TensorFlow from other AI platforms is the fact that it aids in the creation of other AI models that can do and help so much. Using the data from TensorFlow other AI models can be used to recognize patterns and offer sophisticated data. In an industry that relies heavily on data analysis, this feature is huge. Some examples are healthcare, finance, and even automotive.

5.2 Benefits and Drawbacks
AI is taking the world of design by storm, being able to increase efficiency is invaluable and leads to more room for creativity. Simple tasks that are seen as repetitive can now be done by AI so that more complex tasks can be focused on. Using copious amounts of AI can easily do an analysis and provide proper feedback. With all these things considered it is safe to say that AI is not just able to change the way we design but also changing the world day by day. This is not to say that there are no disadvantages or drawbacks that we must face due to AI, all of which will be discussed.

AI has the unique ability to process data much faster than any individual while still offering relevant and intelligent feedback. Excelling at identifying certain patterns and advice on how to create efficient and well-built designs according to whatever specifications it is given. An especially interesting case is the AI algorithms used in generative design, based on given parameters the AI algorithm can come up with different design alternatives that can enhance efficiency, cost, strength, and much more. What this allows designers is to explore new design ideas easily that either a human could not come up with or that might not be immediately apparent through normal means. When discussing AI in the universe of architecture and engineering design, there is a huge department of being able to automate routine tasks like simulating, drafting, and modeling. This is an easy method of speeding up the process but not only that, error is reduced as well. For instance, there are some AI-controlled CAD tools that can create and make tweaks to adjust designs in real time as certain conditions and parameters change. This helps ensure that all specifications are met, and the best part is that manual recalibration is not needed. One incredible feature of AI is its ability to offer users a completely customizable experience that caters to each and every individual based on previous interactions. This proves to be very useful in product design, products can be constructed to meet any requirements and desires of the user. A more specific example would be if we considered urban design, AIs could help to make living spaces more adaptive and responsive and do better at meeting the needs of residents by analyzing live behavior patterns and environmental data. With AI's ability to optimize resource use and decrease waste, we can achieve more sustainable design practices. An example of this in practice is using AI to optimize the use of materials as well as the layout that limits the amount of excess material or waste produced. AI can also extend the lifespan of products by notifying the user when maintenance for said product is recommended.

Now let's talk about some of the potential drawbacks of AI. A major worry right now for AI is the loss of jobs in every market, everyday AI can complete more difficult and tedious tasks. If it were possible for a company to replace employees with AI, they would jump on the chance immediately and that is where the concern stems from. Essentially, what makes AI useful to us can also be what ends up harming us. Another major concern of AI is the loss of human contact on a daily basis. As AI becomes more indistinguishable from humans there is a looming concern that we will be very limited to the real human interactions that we encounter every day. Although AI can be very efficient in completing tasks and providing information, it is not capable of offering a human's complex emotion. Due to AI's nature that requires it to collect large amounts of data, there is also a security concern that comes along with that. What data do AI systems use and is it an ethical method of data use? A substantial number of people today are not fine with how much of our data is used and sold as it is, adding another piece to the equation will only raise more concerns. It is also important to note that based on the data used to train an AI it can develop biases that users may not agree with or like. Being over-dependent on anything is usually not a good thing and the same goes for an overuse of AI. If not properly monitored AI can often produce results with errors in it, even just small errors, that if left unchecked can spread misinformation and cause harm. Also, being overly reliant on AI can develop a sort of lazy tendency in humans and may result in the loss of skills like critical thinking, etc.

5.3 Influence on Our Project

As a small group working on our senior design project, the use of ChatGPT and other AIs has streamlined the working process. Making it easier and more efficient than ever to learn and understand any concepts we have been confused about. The integration of AI into our project has been what feels like the contributing factor to what has kept us ahead of our studies and deadlines. With ChatGPT being almost like a personal tutor we have been able to work more efficiently on more strenuous tasks like designing the PCB.

Let's get into the specifics of how exactly ChatGPT helped in the development of the design of the PCB. Along with helpful YouTube videos and advice, ChatGPT helped advance the PCB design. ChatGPT acted as a tutor whenever there were any questions on how exactly a component or characteristic of a component works in a circuit. One example of this is when I asked ChatGPT for a general description of what standby current is for a voltage regulator. ChatGPT was able to generate a response that showed: the importance of standby current, factors affecting standby current, typical values, and more. Because of this streamlined learning process, I was able to correctly select a voltage regulator that would meet our requirements. Along with the MCU datasheet, ChatGPT also aided the project in helping identify which specifications to look for in each component. Once every component was selected ChatGPT also helped to connect everything together in the schematic along with all the datasheets. With a critical mind and proper checking, we were able to use ChatGPT quickly and efficiently to create a preliminary PCB design.

6.0 Project Hardware and Software Design
Having an overall plan and direction for the project hardware and software design is an important factor in keeping an organized project. Without this then the progress in creating the prototypes and the overall project could be very rough without any proper deadlines or goals that would need to be set for a smooth project. This also allows proper research and thought processes when designing and creating the different aspects of the gun. So when we proceeded to create the first major prototype there weren't any obstacles that weren't properly planned or foreseen that we as a group would come upon when creating that first major prototype. The written sections below represent the research and decisions we have made for the different designs and aspects of the gun and will later influence the overall creation process of the final product.

6.1 3D Phasor/Gun Design
The primary objective of the housing design is to establish a laser tag gun that is capable of simulating our chosen design. It must also be able to have a functional enclosure capable of accommodating essential components of laser tag such as a trigger system, microcontrollers, batteries, and an infrared emitter. These are the basic goals we have established to properly create a laser tag system. Furthermore, beyond these basic goals, we have established possible stretch goals or additional goals that can further enhance the experience itself and improve the overall function of the project.

One key stretch goal includes implementing a LCD display on the gun itself. This display will be able to not only just indicate the progress of the game but also the ammo count and health of the user himself. This possible addition to the game will add another layer of immersion on top of the gun itself.

Another possible goal is the implementation of a reload system. Many already existing laser tag systems also include a reload system but they achieve this by just simply having a button on the side of the gun that will just simply add more shots to their gun. Our goal for this project is to further enhance this aspect by being able to have a separate magazine system in which the process of reloading does not just simply stop at pressing a button. Our plan is to be able to properly unload the magazine itself and put in a new magazine, this process is to replicate the realistic aspect of reloading a gun by having to replace an "empty" magazine. The purpose of doing this is to make the system itself more realistic so it can be better utilized in proper military simulation training.

Furthermore, the design itself can possibly replicate the ability to add various attachments to the gun itself. Examples include scopes, rail guards, foregrips, angled grips, and different stocks. The ability to add attachments can be achieved by utilizing established concepts such as Picatinny rails or M-LOK systems to hold these attachments onto the gun. Firearms in the real world in the world also utilize similar systems to hold attachments like scopes in their designs. Also, the addition of modular stocks would allow us to retain the batteries for the laser gun system inside the stock itself. This would also provide the possibility to change the barrel/shroud to increase the range of the laser gun. This could be accomplished by having a separate modular barrel containing a stronger infrared emitter or a more powerful lens to extend the signal's range. As a result, all of these potential options would create a modular aspect of the design itself, further enhancing the laser tag experience. Each user would be able to create or design their own modular gun, tailoring it to their preferences and playstyle.

6.1.1 3D Printer

There are many different types of 3d printers that we can utilize to print the 3D model for the gun. Out of the many choices, the one we have the easiest access to is the Ultimaker 3 due to one of the members of the group already owning an Ultimaker 3. However even though we have easy access to a 3D printer, it is still vital that we analyze alternative 3D printers outside of the Ultimaker 3. The other alternatives that we decided to explore were the Creality Ender-3 and the Prusa MK4. These printers stand as formidable alternatives, boasting features comparable to the Ultimaker 3 and some having capabilities that exceed the Ultimaker 3. But of course, due to not owning any other alternatives outside of the Ultimaker 3, the group would have to include the 3D printer in the budget and due to the high price of the printers, it would affect the overall budget throughout the project. This can cause budget issues where other areas of the project need to be decreased in price to further afford to buy a new printer. And as such we also need to consider customer support in the case of possible malfunctions with the printer.

Table 16. 3D Printer Comparison

Features	Creality Ender-3	**Ultimaker 3**	Prusa MK4
Price	$200	**$3000**	$799
Print Speed	50-60 mm/s	**40-75 mm/s**	50-80 mm/s
Travel Speed	180 mm/s	**150 mm/s**	600 mm/s
Wall Thickness	0.4 mm	**0.4 mm**	0.4 mm
Extruders	Single Extrusion	**Double Extrusion**	Single Extrusion
Heated Bed	>= 110 Celsius	**>= 135 Celsius**	>= 120 Celsius
Bed Size	220 x 220 x 250 mm	**230 x 190 x 200 mm**	250 x 210 x 220 mm

The Creality Ender-3 stands as a very budget-friendly option and still compares to the other printers as a contender in the 3D printing world. Even with its very highly affordable cost, it provides great versatility and is overall extremely popular among 3D printer users. It is also known to be extremely robust and has an extremely high durability that allows the printers to continue even when encountering an issue or printing poorly. One of the defining features of the Creality Ender-3 is its ability to be easily modified or have many modular parts that can be changed or replaced. These changes also boast a fairly affordable price allowing you to easily modify the 3D printer to the specifications you might need for the project. Overall the Creality Ender-3 stands as a very possible option that we need to consider for the project and with its cheap and affordable price of $200, it stands against giants like the Ultimaker 3 and Prusa MK4.

The Prusa MK4 continues its legacy from the Prusa MK3 which as a result improves on the already very robust and well-rounded Prusa MK3. One of the greatest factors that the Prusa MK4 continued to improve on was its very friendly interface and easiness of printing a model that the user has designed and wanted to print. Like the Creality Ender-3 and Ultimaker 3, it contains a fairly well-sized heated bed and versatility in its ability to print different types of filament when considering the situation or environment that the model would be used in. Also, its commitment to being an open-source project allows many different users to troubleshoot and allows support between the different users in the community. Further enhancing the support of the overall 3D printer by simply not restricting and even further fostering support between the members and users that use the Prusa MK4. In the end, the Prusa MK4 stands as a very high quality and high-performance printer that was considered when choosing what 3D printer we will utilize within our project.

The Ultimaker 3 boasts a very precise ability to print and also the ability to dual extrude allowing for either two colors or two different materials to be printed at the same time. It is the ideal printer for this project since it allows very precise printing that is necessary to show all the details on the gun. Also with it boasting a high ability to print with large overhang, the need for supports to be within the design is lessened and a more accurate and smooth look to the gun can be achieved. Also having personal access to an Ultimaker 3 would ensure a seamless workflow and also allow efficient production and testing with the design. As a result, we will be able to achieve the desired aesthetic and design we want for our laser gun model. Overall the Ultimaker 3 is a great choice for a 3D printer due to the combination of accessibility, versatility, and reliability and will allow us to create the 3D housing for our laser tag system.

6.1.2 3D Modeling Software

In terms of 3D Modeling Software, there are a lot of different options that we can use to CAD the 3D model of the gun. Some options are Fusion 360, AutoCAD, SolidWorks, Creo, or Onshape. Each one of these programs boasts different tools and capabilities when designing your own 3D model. Most have access to possible AI assistance and most of the programs boast about having very high customer support whenever the user needs assistance. Also, most of the programs have an expected skill level of professionalism with the exception of Onshape which was mostly created for students or hobbyists trying to learn and understand the capabilities of CAD and how to use it to create a 3D model for their own personal use. One major issue that we must analyze is the possible cost of using some of these programs and the different possible ways we can use to get the program at a lower or free cost.

Table 17. 3D Modeling Software Comparison Table

Features	AutoCad	SolidWorks	PTC Creo	**Onshape**
Cost	Annual subscription of $2030	Annual subscription of $2820	Annual subscription of $2950	**Free of cost**
Access to Cloud	Yes	Yes	Yes	**Yes**
Expected Skill Level	Professional	Professional	Professional	**Hobbyist**
Automation or Access to AI	Has access to AI assistance that could possibly assist with automation and insights	Has access to AI-powered design tools	Has access to AI-driven generative design	**Has access even though minimal to AI-driven generative design**
Customer Support	High customer support including possible calls or appointments	High customer support including possible calls about installation	Basic customer support including possible calls	**Minimal customer support with no support over the phone**
Program or Web	Program and Web	Program and Web	Program	**Web**

AutoCAD is a very well-known program for creating CAD models in the professional world. This program boasts high versatility, high precision, easy customization, and easy visualization with its high-end rendering tools. Also, its ability to integrate other AutoDesk software and third-party applications offers a high level of collaboration between different platforms so users can easily import and export files. As such when designing CAD models, it is very easy to import reference materials when creating the model. It also allows scripts or plugins using the AutoLISP or .NET languages so the user is able to customize the AutoCAD program to their own liking. But even with all these advantages, AutoCad still has a fair amount of disadvantages when using the program. One of these disadvantages that really needs to be considered is the high cost of purchasing the program the inability to make a one-time purchase and the requirement of a subscription. Also, AutoCAD is mainly used for professional use meaning that the learning curve to use the program is extremely high and it is extremely complicated to use as a beginner, student, or hobbyist trying to get into 3D CAD model creation.

SolidWorks is another program option for creating CAD models, similar to AutoCad and PTC Creo, this program is mainly used and seen in the professional setting. One of the features that SolidWorks is well known for is the extremely powerful parametric modeling which allows users to create very complex 3D models with ease. Any changes or visions for the 3D model are effortlessly created or envisioned when using the many different tools that SolidWorks provides. It also contains a very user-friendly interface where it is easily used and learned by not only experienced professional users but also beginners trying to learn how to create a CAD model. Its ability to also create simulations allows the users to better visualize how the CAD model will work in the expected environment and how different parts of the model will function when utilized in real life. But similarly to AutoCad, it contains a fair amount of disadvantages, one of these disadvantages is the annual cost to use the program. For this project, we will not be able to afford the annual cost of the program and need to look into possible sources of the program when using our student identities. Also, SolidWorks is known to have poor MAC support since it is primarily designed for a Windows operating system. This will hinder our progress if one of our group members utilizes the Mac operating system instead of a Windows operating system.

PTC Creo is also a fairly well-known program in the world of CAD model designing. The program itself is similar to SolidWorks and AutoCad where it has its own very complex tools and provides robust but not complicated parametric modeling tools allowing the user to create complex 3D models with ease. It also provides access to other possible designs such as 2D sheet metal designs, assembly modeling, and the basic CAD part modeling. The program also boasts a very advanced simulation and analysis which could be seen when one of the members of the group previously utilized the program for the FIRST robotic competition. Its ability to create advanced simulations further enhances and improves its ability as a robust CAD program. But of course, like the previously analyzed programs it contains a very high starting cost requiring you to subscribe every year instead of purchasing the whole program once. Also due to its advanced simulation capabilities, it requires a high-performance computer with sufficient specifications that can run the program. PTC Creo itself is a very resource-intensive software and like any other resource-intensive program, is very prone to crashes or glitches while using the program.

The option that our group decided to utilize is Onshape due to being free for students and the ability to share and export freely between the members of the group. There is also no need to download the software on your PC as the program can be utilized through your browser. Hence allowing you to work on the CAD design from anywhere you want and from any computer that you have access to. The requirements for running the software are outlined below in Table 18.

Table 18. Requirements for Onshape

Operating Systems	macOS version 10.12 or higher, Windows 7 or higher
Browsers	Google Chrome, Mozilla Firefox, Safari (Mac OS only), Opera, Microsoft Edge (Not including Microsoft Internet Explorer)
Graphic Card	512MB GDDR 4GB Dedicated
Memory	~3 GB
Internet	DSL or faster

All guides for the Onshape Cad software can be found not only on internet sources such as YouTube but also on the dedicated guides that are created by the Onshape team. Some of the tools on Onshape are very similar to other tools found in other software so there will be a little bit of getting used to how Onshape works as compared to other software for the members of the group that has some experience with 3D modeling.

Our plan with Onshape is to properly model all the different components that we are using to properly test the design in a virtual setting. Then we can implement it together after printing all the 3D models in real life. This way we can resize the housing without having to constantly print and test the shape of the housing. Also, the ability to share the project with the other group members over the cloud will allow an easier explanation of the overall design as a group.

One of the issues with 3D CAD design and 3D printing is the problem of any slight change with the design in the CAD design will require a complete reprinting of the physical 3D Model possibly taking up to an entire day to print. This also includes needing more filament to print the new changes and also the scrapping of the previous prototype since it would not contain the new changes. This can occur for a big change in the design but also for even a very small change in the design. This is hopefully minimized by separating each major part of the gun into smaller pieces. So instead of having to completely reprint the whole model, we can just reprint the small part that we changed and apply it to the complete design.

6.1.3 Phasor Theme

One of the major components of this project is the aesthetics and looks of the laser gun design that we chose to create. There are many different options and aspects that we can apply to the design. For instance, the gun can adopt either a realistic or futuristic theme for the overall design. The realistic theme can replicate some real-world gun designs so when used for military simulation it would provide the correct authentic feel for military training. But this can also possibly introduce some safety issues where having a too-realistic gun can cause fear and panic if seen in a public situation. Conversely, a futuristic gun design with a more toy-like look would induce less fear than a realistic gun but there are still many different aspects that we need to look into.

A realistic design for the gun design would make the goal of creating the project for a military training simulation more achievable. It would also add a more immersive feel to the laser tag system as for many laser tag enthusiasts, many would like the tactile feel and appearance of a realistic copy of a firearm. Also, the aesthetics of the whole design would add a more enticing feel to the system if applied to the market. Of course, due to making the gun more realistic, there are many different constraints that we must follow in the designs. Such constraints could include legal and safety issues if seen with the 3D model in public. A realistic model of the gun can lead to panic or alarm if seen by others and result in a large issue for the user. Also, many different laws are preventing open carry of a firearm, and making the gun too realistic can make it get mistaken as a real firearm. Also for another issue with making a realistic gun model is the stigma or perception that firearms are a negative symbol of violence and aggression. Leading to possible issues if our group decides to push the model to the real-world market.

A futuristic design veering toward a more toy-like appearance would solve many of the issues that come with a realistic design. Opting for a futuristic toylike appearance would prevent the situation of the model being mistaken for a real firearm hence reducing the potential safety concerns when bringing it out in public. Also with a futuristic design, we are allowed any sort of design for the gun and not forced to follow the basic format that a real firearm would follow. We can easily include many lights, colors, shapes, or unique elements that would typically not be seen in a real firearm. Also, the whimsical design of a futuristic toy-like appearance may appeal to a broader audience such as younger families and children. The more we avoid the realistic gun model design the more family-friendly the laser tag system becomes since it becomes more approachable. But even with these really strong strengths with a futuristic toy-like design, there are many other issues such as lack of authenticity as it may look too much like a toy and lack the appeal of a somewhat authentic military simulation at home. Also, some older audiences might view the laser tag system as childish and immature as the gun model itself is meant to look more like a toy. Another issue that we need to address is that we will need to personally create the design of the gun. Unlike a realistic model of a gun where we can use guides or pictures of the real firearm as a guide to the design of the CAD model. This will require creativity and innovation to develop a model that stands out from existing designs

For this project, we decided if we can and the ability to, we would like to create two different models for the gun design. One that is fairly realistic and can be used for military simulation and training. Another one is that it is more toy-like and can be seen as more easily approachable for hobby or home use for children. We would like to make our systems more well-received by all audiences or people interested in our project.

6.1.4 Phasor Designs

Considering the overall shape of the gun model for the laser tag system goes beyond just aesthetics and designs, it also involves the functionality and practicality of the system. Real-life firearms are typically cataloged into groups such as pistol, rifle, submachine gun, and sniper. Each one of these has their strengths and weaknesses to their design. It is vital to choose a design that would best fit our project and properly cover all requirements that we need the housing to have to complete our laser tag system.

Table 19. Gun Design Comparison Table

Features	Pistol Design	Rifle Design	**Smg Design**	Sniper Design
Size and Portability	~5 x ~5.5 inches and High Portability	~27 x ~9 inches and Low Portability	**~17 x ~9 inches and Medium Portability**	~43 x ~7 inches and Low Portability
Complexability	Low due to small size and simple overall design	High due to many different designs and possible additions	**High due to many different designs and possible additions**	Medium due to different designs
Possibility of Internal Space	Low ~5 x ~2 inches	High ~27 x ~5 inches	**Average ~17 x ~5 inches**	Average ~43 x ~4 inches
Possible Attachment	Ability to add sights and barrel attachments	Ability to add sights, stocks, shroud attachments, barrel attachments	**Ability to add sights, stocks, shroud attachments, barrel attachments**	Ability to add sights and barrel attachments
Overall Style (1 - 5 rating)	Simple design 2 rating	Complex Design 5 rating	**Complex Design 4 Rating**	Average Design 3 rating

A pistol design would make the overall CAD model fairly simple to design as the pistol is typically a fairly small object. As a result of its small size, it is very portable and easily carried around when playing laser tag. Also, a pistol would cause a little bit less panic as compared to a rifle in public. The shape of the pistol also seems more accessible as new players can easily understand how to utilize the pistol and would be less scared to play with it. But of course with its small shape, it comes with a lot of issues when trying to implement it into laser tag. Due to its small frame, it would be very hard to place the components inside the pistol and the batteries themselves can't be too big. Also, there is less of a chance to customize the gun when adding attachments as even in real life the pistol has a very small capability to customize using attachments.

A rifle design would solve a lot of the issues that a pistol design consists of. One of the problems it solves is the increased size resulting in more space in the housing. This additional room allows for better organization and integration of essential elements, contributing to the overall efficiency and performance of the laser tag system. Also due to the rifle being one of the most recognizable gun designs in the real world, it would be fairly recognized and would easily allow the experience to be more immersive. There are also many different rifles in the real world that we can use to base our 3D model on. Moreover, the inherent capability to customize real-life rifles would apply to our own 3D model laser tag rifle. As a result, being able to accessorize your own rifle, would further enhance the user experience by providing different options for how they want to design their rifle. But of course, since the rifle is the most recognizable shape for a firearm, if seen in public would cause panic as many would mistake it as a real firearm. This will introduce the issues of the many different safety additions we would need to make to prevent such panic in public. And with how large some rifles can be, it would be very hard to safely transport the prototype model to test or even to play in public.

A submachine gun or SMG design would be the middle ground between the pistol and rifle design. An SMG would be easily portable and still contain a plentiful amount of space for the housing of components. The shape of the SMG would also allow all users to easily wield and use the laser tag gun. The SMG also boasts about having the same amount of capability to customize as the typical rifle design. It is also mostly used and associated with military or law enforcement which would allow the project to be used for military or law enforcement training simulations. One drawback to consider is that the SMG doesn’t conform to the typical firearm design that people envision when thinking about firearms. Unlike the universally recognized pistol and rifle designs, the SMG may be less familiar to many individuals. As a result, some players may feel less immersed in the game with an SMG, as it may not evoke the same sense of realism and authenticity as other firearm models. This lack of familiarity could potentially detract from the overall gaming experience, particularly for players who value a high level of immersion and realism in their gameplay or military training and want to achieve the highest level of realism.

Opting for a sniper rifle design could offer unique benefits for the gun design, despite being less typical for a laser tag system. One advantage is the distinct tactile feel of a sniper rifle compared to more common rifle or pistol designs. The longer barrel, optics, and specialized shape of a sniper rifle could provide players with a different and potentially more immersive experience. Additionally, sniper rifles play a crucial role in military operations, with specialized positions dedicated to marksmanship and long-range shooting. Incorporating a sniper rifle design into the laser tag system could better simulate military training scenarios that require precise target shooting over long distances. This could enhance the authenticity and effectiveness of training exercises, particularly for military training in marksmanship and reconnaissance roles. Overall, while a sniper rifle design may not be the most typical choice for a laser tag gun model, it offers unique advantages in terms of gameplay experience and simulation. By carefully considering the benefits of a sniper rifle design, we can apply such benefits to the final gun design furthermore enhancing the realism, functionality, and player experience.

In conclusion, the shape design that we decided to utilize is the Submachine Gun or SMG. The SMG design emerged as the most suitable choice as a result of its compact size, ease of design, and customization. Additionally, the shape itself would cater not only to the military personnel for military simulation training but also to the hobbyist playing laser tag in their backyard. Overall the SMG design shape includes the most benefits as compared to the other options and at the same time accomplishes all requirements necessary to implement the laser tag system and enhances the user's experience and overall enjoyment of the laser tag system.

6.1.5 Possible Materials

The material used for the laser tag gun housing is a vital aspect of the project as the material itself needs to be very durable and portable to be able to be utilized for our laser tag project. The material itself cannot be too heavy as it would be impossible to carry and utilize. This will prove difficult as a lot of stronger materials such as metal are inherently heavy and will also add another level of difficulty when trying to shape and create the housing for the gun.

Another option would be wood as it is very simple and easier to use to create the housing for the gun. It is also easier to shape and even easily accessible as a simple hardware store will be able to sell you wood. However, opting for wood as the primary material presents challenges, especially when considering the need to contain essential components within the gun housing. Wood's inherent limitations in terms of strength and precision may pose difficulties in securely holding and organizing the intricate array of components required for the laser tag system. Despite its ease of shaping and availability, wood may not offer the structural integrity necessary to support the functionality of the laser gun and ensure the reliable operation of its internal mechanisms.

An additional possible material that we have considered is the utilization of plastic or foam for the final material. But both of these prove to be difficult as plastic is hard to use as a material as there are many different steps needed to properly shape and create the design. Especially when we need to make a cast model for the gun to properly melt the plastic and shape it around the cast. And with the other option foam, even though it may be very easy to shape the model with foam. We will have the drawback that foam as a material itself is not very durable and very likely to break during testing or use as the final material. As such all the previous materials considered even though having very strong strengths, would not be viable as the final material chosen to create the gun.

Table 20. Housing Material Comparison Table

Features	Metal (aluminum)	Wood	Foam	**Plastic/3D Printing Material**
Durability (tensile strength)	~70 to ~500 MPa	~50 to ~250 MPa	~1 to ~10 MPa	**~40 to ~55 MPa**
Ease of use	Requires heavy machinery	Requires simple home machinery	Could utilize basic household tools	**Requires 3D printers and filament**
Cost	24 x 60 x ⅛ inch sheet ~$56	4 ft x 8 ft x ⅜ inch sheet ~$27	36 x 48 x 3/16 inch sheet ~$11	**1KG PLA filament roll ~$20**
Safety	Dangerous, could cause bodily harm and major cuts	Semi Dangerous, possible wood splinter or cuts	Not dangerous to handle but chemically dangerous	**Very little to no danger**
Weight	168.4931 pounds per cubic foot	25 to 70 pounds per cubic foot	~4 pounds per cubic foot	**~70 pounds per cubic foot**

After analyzing and reviewing the different advantages and disadvantages of the four different materials, we decided that plastic or 3D printing materials were the best chosen for our project. This decision was made based on the fact that it is a fairly cost-efficient material that still holds a fairly good durability. It is also chosen for its ability to be able to shape and utilize the material easily through a 3D printer. But even though the use of a 3D printer would introduce the problem of having to create a CAD model for the design, it would allow us to make changes easily and reproduce possible copies when making multiple models for different users to play with. Also, there are many different types of 3D printing filament with different strengths and utilization that will be analyzed later in the report.

6.1.6 3D Printing Materials

As stated before after analyzing the previous different materials we have decided that using plastic or 3D printing materials is the best chosen material for this project. PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), and PLA-CF (Carbon Fiber Reinforced PLA) emerged as possible candidates, each with its unique advantages and drawbacks. By exploring these 3D printing materials, we aim to identify the most suitable option that fulfills the project's requirements for durability, functionality, and realism in the laser gun's physical design.

Table 21. 3D Printing Materials Comparison Table

Features	**PLA**	ABS	PLA-CF
Cost per KG	**$20 to $30**	$15 to $25	$25 to $35
Strength	**39.9 to 52.5 MPa**	29.6 to 48 MPa	45.5 to 57 MPa
Ease of Printing	**Easy to print requires no extra steps**	Easy to print requires no extra steps	Difficult to print requiring possible troubleshooting and cleaning of nozzles
Print Temperature	**180 to 220 Celsius**	220 to 250 Celsius	200 to 230 Celsius
Environmental Impact	**Biodegradable**	Non-biodegradable	Biodegradable
Post Processing	**Easy no extra work**	Requires acetone to modify	Needs extra post-processing due to carbon fiber
Warp Resistance	**Very likely to warp requiring a particular printing environment**	Very unlikely to warp and very resilient during printing	Very unlikely to warp and very resilient during printing
Printing Surface	**Heating bed recommended**	Heating bed recommended	Heating bed recommended

Polylactic Acid or PLA is derived from renewable resources such as cornstarch or sugarcane, making it extremely environmentally friendly and biodegradable. It also has a very low melting point which will improve the quality of the printing process as it reduces the risk of warping during printing. As a result, this will assist the printer in having a smoother and more precise print that has less of a chance of having a drastic failure during the process of printing. Additionally, PLA emits less unpleasant and toxic odors during printing as compared to other materials like ABS. However, PLA also has its drawbacks. It has a lower heat resistance being able to melt on a very hot day therefore limiting its usage in environments with elevated temperatures. Also since it's very environmentally friendly and biodegradable, it is not a very good material to leave outside without protection as it will accelerate its rate of biodegradation over time.

Acrylonitrile Butadiene Styrene or ABS offers many advantages when used as the main material for gun design. It boasts very high durability and impact resistance making it a very good choice for rough play or outdoor play. This can be useful as the laser tag system in a military simulation setting needs to be very durable and strong for simulations in rough environments. It also has excellent temperature resistance making it very viable to use outdoors. However even with these very strong advantages still contains many other drawbacks. One such drawback is that it emits very toxic and potentially harmful fumes while printing. As a result, when printing the 3D printer itself requires proper ventilation to reduce health risks. Also when printing, ABS is very prone to shrinking and warping while cooling which can lead to distortions or deformation of the final printed object. It has also been researched and seen that many printers have difficulties printing with ABS as a result of its high tolerance to elevated temperature.

Carbon Fiber Reinforced PLA or PLA-CF combines both advantages of PLA and ABS, PLA-CF retains PLA characteristics of being biodegradable but also retains the ease of use when printing with PLA. It also still has the durability and high-temperature resistance that is commonly seen in ABS. These advantages are a result of containing carbon fiber in the already resilient PLA. However, as a result of containing carbon fiber in the filament, it leads to possible wear and tear on the 3D printing equipment. These repairs can be very expensive and result in further issues with future prints. Also, the filament itself is usually very expensive compared to the standard printing material of ABS or PLA. Even with these drawbacks, PLA-CF proves to be a very reliable material to print and use as a final material for our project.

In conclusion, after looking at all the options, the 3D CAD model will be printed with PLA. It is considered one of the cheaper options listed and will be very easy to use when printing the model. PLA was chosen over ABS due to the many difficulties the 3D printer would experience when using ABS. Considering the many different prototypes that we might need to print, it would cause great difficulties if the way through the print fails. Also, PLA is a very liked material that many different 3D printer owners have used which means that if our project encounters any difficulty while printing it would be fairly simple to troubleshoot online.

6.2 Printed Circuit Board (PCB)

The PCB is the main connector of components in this project. The main goal on the hardware side of our project is to design an advanced PCB that is compact and effective. The PCB will connect the MCU, any controllers, and the WIFI module so that they can efficiently communicate with each other. The reason for the requirement of the PCB is for the optimal design that is an industry-standard. We plan to make our PCB single-sided with one copper layer since we have a low component density.

Development and design of the main PCB will be done using the Autodesk Eagle software as this is also industry standard, but before starting any design the parts will be chosen to see which are available for order. Eagle offers a wide range that aid in the designing of the PCB: the layout editor which supports complex board designs over multiple layers, the schematic editor which makes it easy to draw any circuit designs, and the huge library of component footprints that already exist in EagleCAD to name a few things. Once the design has been checked and validated and the manufacturing files have been generated, we can select a PCB manufacturer to be able to get the physical board. RushPCB is one of the manufacturers we are looking at to help the creation of this board come to life.

The PCB's main purpose is to connect the internal components such as resistors, capacitors, integrated circuits, etc. by physically attaching them to a substrate; this is done in an organized manner to make their interconnections a much simpler process. Another functionality of the PCB is to distribute the power provided by the source to the various other components connected to the board. This means the voltage and current levels need to be tuned properly for each component to operate correctly.

Now, when discussing the importance of the PCB to the final design we need to understand what advantages a PCB offers. A PCB connects different components with a designed layout using etched copper tracks. When a circuit becomes more complicated and requires more time and wiring to develop, a PCB is the only feasible option as its compact and reliable design makes connecting the different components a breeze. In addition, a PCB allows for the minimization of interference, noise, as well as signal loss with careful calculation of the trace layout; all of which is vital for the successful operation of electronic components at high speed and high frequency. Once we start dealing with high-power components the heat generated by these components is something that needs to be properly dealt with, PCBs allow for the use of copper traces, thermal vias, and heatsinks to deal with said issues. In today's technological world, we have automated the process of creating PCBs allowing for mass production thereby reducing cost and increasing production of electronic devices. To sum it all up, a PCB is so important because of the advantages it offers over other methods: facilitating electronic connections, ensuring signal integrity, power distribution, heat dissipation, compact and reliable designs, and cost-effective manufacturing. It is also important to note without a functioning PCB the entirety of the project will not function, therefore making it single-handedly the most crucial piece. When connecting the different components to the PCB, we must figure out what other kinds of circuits will be required to ensure everything is functioning properly. For example, the MCU will require a voltage regulator to provide stable voltage levels to it as well as the other components. A Power Management IC (PMIC) is another circuit that would come in handy in controlling and managing a system's power requirements. When we need to decouple different ICs or regulate any fluctuations in the power supply, we can use the capabilities of filtering capacitors. Additionally, we will utilize a display interface such as an LCD display.

Furthermore, there are certain qualities that make it possible to integrate all our components: MCU, RGB controller, and Wi-Fi/Bluetooth module using a PCB. Conductive traces and pads are essential as the traces as the electrical wires on the board and are the means of connecting different opponents. The pads, however, are small areas of copper exposed for component leads or pins to be soldered to; these are designed to be the physical points of contact between the PCB and its components. Layering is an essential feature of the PCB as it allows multiple conductive traces connected to each other and separated by an insulated material. The advantage of layering is that different layers can carry different signals and power levels; a more compact design with more complicated circuitry is the result of this PCB quality. Moreover, we also have the use of vias: through-hole vias and blind and buried vias being the common way of use. While through-hole vias allow for the interconnection between different layers of the PCB the blind and buried method does the same but does not need to completely pierce both sides of the PCB. To create a secure electrical connection for each component in the PCB we must design a designated spot for each component and solder each component in their corresponding location. Similarly, silkscreen is strongly suggested to be used as a means of identifying component locations and orientations, printing labels on the board, and adding any other information that the designer deems helpful. Although not necessary, the importance of this feature can be most appreciated during assembly and troubleshooting. Something often overlooked when talking about PCB creation is the surface finish applied to the copper traces and pads to prevent oxidation and improve solderability, thus improving long-term durability. Finally, it is important to note that including many test points to allow for electrical testing to make sure all connections are working and there are no short or open circuits is highly recommended.

Table 22. PCB Comparison Part 1

Feature	**PCB**	**Breadboard**	**Perfboard**
Nature	**Permanent**	Temporary	Semi-permanent
Assembly	**Soldering components to a custom-designed board**	No soldering, components are pushed into spring clips	Soldering components through pre-drilled holes
Flexibility	**Fixed design; changes require a new board**	Highly flexible; easy to add, remove, or change components	Flexible; components can be rearranged by soldering
Durability	**High; designed for long-term use**	Low; repeated use can wear out connections	Moderate to high; depends on the quality of soldering
Complexity and Scalability	**Suitable for complex and scalable projects**	Best for simple to moderately complex prototypes	Suitable for moderate complexity; scalability is limited
Cost for Prototyping	**High initial cost for design and manufacturing**	Low; reusable for multiple projects	Low to moderate; depends on the size and material
Lead Time	**Long, includes design, fabrication and shipping**	None; available for immediate use	None to low; requires manual assembly

Table 23. PCB Comparison Part 2

Feature	**PCB**	**Breadboard**	**Perfboard**
Design Visibility	**Low; components and traces are fixed, making troubleshooting harder**	High, easy to visualize connections and make adjustments	Moderate; easier to trace connections than PCBs but harder than breadboards
Suitability	**Final product or advanced prototypes**	Early-stage prototyping and learning	Intermediate prototypes or when a more durable solution than a breadboard is needed without the full commitment to a PCB

6.2.1 PCB Design Software

As simple as it may seem, which PCB design software you choose affects the efficiency, accuracy, and design process for a project. EagleCAD and Altium Designer are industry favorites so we will be going over those, and EasyEDA is a popular choice among the project-building community so we will discuss this software as well. Each program has unique features and has different benefits for different use cases.

First, we are going over what benefits Eagle offers over the other software. EagleCAD's strong suit is how simple it is to start using the software while still offering benefits even to professionals. What makes Eagle user-friendly is the simple UI that doesn't overcomplicate the design process; the very intuitive menu makes it very easy to navigate. This makes it much easier for users to take an idea on paper to a schematic and PCB layout in no time and with ease. Another major benefit of Eagle is its deep library of components which also adds to the simplicity. These are pre-loaded libraries on the software immediately ready for the user to input as needed, ranging from simple components like resistors and capacitors to complex ICs. This is huge for users in the preliminary process making it much more efficient. Eagle Library is also customizable if an individual needs to add their own components. With the popularity of Eagle, there is a very strong community behind it. Many forums of experienced users offer their knowledge and tips to the rest of the community, constantly sharing their ideas and findings. The internet is full of tutorial videos for Eagle as well. Professionals can also communicate on these forums to discuss complex issues and offer their solutions. Collaboration is an important factor in the process of self-improving and learning and EagleCAD does it very well.

The main drawbacks of Eagle are more situational and really depend on what you are looking to do for your own project. For some users the simple approach is very inviting and exactly what they are looking for, but if someone is looking for more advanced features Eagle may not offer what they are looking for. Advanced engineering projects may require a more complex feature set that Eagle just does not offer. One example is routing in Eagle, other software offers a much more sophisticated auto-routing feature while Eagle's is quite primitive. Board limitations are also something to be considered since the free version of Eagle has a restriction on the size of the board as well as the number of layers. The maximum board size in Eagle for free users is 80 cm^2 and the amount of signal layers allowed is 2. For any small businesses or project makers this is a concern when trying to create more complex circuitry. In order to have more freedom with board design users need to purchase the license for Eagle which may not be as cost-effective as using other software that offers more features for free. One thing that should also be considered is when trying to make the transition from beginner circuits to more advanced circuits on Eagle the transition is not always smooth sailing. While Eagle's interface is nice and simple, that means that for some of the more advanced tools there may be a stepper learning curve understanding since these features aren't as intuitive or less detailed than needed.

EasyEDA has many advantages over other PCB design software since it is web-based and is accessible from anywhere and does not require a download. With EasyEDAs incredible accessibility users can choose anywhere to work on their design projects if they have an internet connection, there is also no limitation to which devices they can use. This gives users the decision of when, where, and how they want to work. For teams that face a location barrier, EasyEDA is a great option since teams can collaborate in real time with no installation or configuration process needed. One of the largest benefits that attract users to EasyEDA is the ability to view and edit a document with other users together at the same time, like Google Docs or any other collaborative software. This collaborative process helps increase efficiency when developing a design with things such as reviewing and editing and can often result in significant time being saved. EasyEDA also automatically saves and changes made and stores all the saves to be able to make sure the team can go back if any mistakes were made or if they want any changes reverted. Another huge advantage that comes with the use of EasyEDA is its direct link with one of the largest PCB manufacturers: JLCPCB. This makes it so users can order their PCBs immediately after they're done designing directly on the platform itself. Not only that but EasyEDA is able to ensure that your design is capable of being manufactured with JLCPCB before ordering, significantly helping to reduce any mistakes or errors in the ordering process.

However, EasyEDA does have limitations that may make it difficult or even impossible for some users to work with. Unlike other platforms, EasyEDA is reliant on the fact that the user has a stable internet connection. In many parts of the world a stable internet connection may not be easy to obtain, also when traveling there is often not a steady internet connection to rely on. If there happens to be a loss of connection before the software has automatically saved there could be a loss of work, and of course with no connection no projects can be accessed. Being a web-based tool also comes with occasional performance issues that a desktop platform usually performs better in. The performance issues are usually not a problem at all unless we are dealing with larger or more complicated PCB designs. Even if EasyEDA is downloaded, many of its features are restricted when there is no internet connection. Meanwhile, other desktop applications offer very capable and powerful offline versions. Without connection projects are very limited in what they can do.

When it comes to industry standards for PCB designing software, Altium Designer is at the forefront. Altium is often regarded as a premium PCB design software and offers a wide range of features that are well thought out and tested. One thing that is time consuming for any PCB design is routing all components on a PCB layout. Most software auto-routing technology is usually lackluster or problematic. Altium bread and butter is its very advanced auto-routing that are specifically built to be able to handle large multi-layer boards that are also complex with ease and high precision. The advanced auto-routing can optimize a complex layout that also minimizes different interferences like crosstalk and EM interference. This is something very important when developing high-speed circuits. Another feature that makes Altium separate itself from other design software is its comprehensive simulation tools. With so many simulation options designers can easily test their circuits in whichever environment and situation they chose. With whatever conclusions they make from the simulations they can implement changes and advancements to their designs until they reach the result they want. This type of deep analysis also helps to reduce the testing and errors made when trying to manufacture the actual board. Some examples of these simulations include simple DC analysis, complex signal integrity models, even thermal simulations. All saves time and resources when doing prototype revisions. Mechanical design is one aspect that always needs to be considered when designing an electrical product, Altium offers a huge advantage in its strong integration with other mechanical CAD software. With this integration, any design project can be secure in its confidence that a PCB will fit in whatever enclosure was built for it and its alignment with the other components. This is yet another feature that reduces design errors that as a result would end up wasting more time and money. Altium also has a huge component library with all kinds of details to help the user. There is also a tool called "ActiveBOM" that gives the user a real-time analysis of pricing and availability from suppliers. This helps reduce delays when it comes to ordering the final PCB design.

Although Altium is the preferred software to use by professionals there are certain characteristics that make it a less desirable choice for many users. While other software offers free versions like Eagle and EasyEDA, Altium not only has a steep initial cost but also requires a subscription free for ongoing support. For hobbyists and smaller projects and businesses, this cost often acts as a barrier and is often the reason other software is preferred. Altium's extensive features make it a very useful software for professionals, but for new users these features can be overwhelming and add confusion to the whole experience. To fully understand and be comfortable with Altium there is a requirement of time and effort. Another barrier that users may face when using the software is the high demand for power Altium requires, especially with larger, more complex PCB designs. Designers often need a high-performance PC to run the software smoothly and without problems, this again adds to the expense of being able to effectively use the software.

Table 24. Design Software Comparison

Feature	**EagleCAD**	**EasyEDA**	**Altium Designer**
Platform	Desktop (Windows, Mac, Linux)	**Web-based (All major browsers)**	Desktop (Windows)
User Interface	User-friendly for beginners	**Simple and accessible, good for collaborations**	Complex, feature-rich
Component Libraries	Extensive, with community contributions	**Integrated with JLCPCB, extensive**	Very comprehensive, includes supplier links
Routing Capabilities	Basic auto-routing, manual routing tools	**Decent manual and auto-routing**	Advanced auto-routing, superior manual tools
Simulation Tools	Limited simulation capabilities	**Basic simulation features**	Extensive simulation capabilities, including thermal and signal integrity
Integration	Limited external integrations	**Strong integration with JLCPCB for manufacturing**	Excellent CAD integration for mechanical co-design
Pricing	Free version available, paid licenses for more features	**Free to use, pay for advanced features and manufacturing**	High cost, subscription-based licensing
Performance	Good performance on standard hardware	**Dependent on internet speed and browser**	Requires high-performance hardware

In summary, all PCB design software has their own pros and cons and offers their own unique experience that benefits some users more than others. For example, EagleCAD is robust and gives its users, both experienced and new users, the tools they need to succeed through the entire design process. This is done through a great ecosystem and support from the community. It is important to remember that even with these benefits, there are limitations to the Eagle that should be considered: high-level automation, simulation capabilities, or more sophisticated PCB designs. On the other hand, EasyEDA is very good at offering a great collaborative experience with a simple transition from design to production and manages to do it all very cost-effectively. However, there is the unfortunate situation that requires a good internet connection to have a reliable experience on the software and the fact that more advanced designs may experience more performance issues. The last software discussed, Altium designer, clearly offers the most professional experience with the widest range of features, but this comes at a high cost and level of complexity. In the end, we decided that EasyEDA would be the best option for the project since it offers the most streamlined experience from design to actual production, has a highly collaborative and simple experience, and is one of the cheapest options that we could choose.

6.2.2 PCB Design Philosophy

The PCB will be designed around the idea of being compact and as cheap as possible while still being able to carry all functionality and maintaining durability. Ease of the manufacturing process is also something very important to the project. Because of this we make sure to design the PCB in such a way that is easy and cost-effective for manufacturers to make. Another design principle we choose to follow is to design for testability to make sure we can easily test and troubleshoot our PCB. This process involves adding test points, getting the proper testing equipment, and making sure our component placement is easiest for testing. The minimization of noise is a necessary design process to prevent degradation of a circuit. Through good practice with trace routing, shielding, grounding, and decoupling capacitors, we can minimize the effects of noise and interference. We also choose to follow proper thermal management so that our PCB performs properly within all ranges of expected performance. Heat sinks, thermal vias, and proper placement, are all valid methods of ensuring full reliability. Making sure to comply with any standards for PCB will also aid us in our efforts and ensure compatibility with different components as well as compliance quality and safety regulations. Finally, making sure our design is optimized for an efficient assembly and making good use of simulation tools is helpful in reducing wasted time, errors, and cost.

6.2.3 PCB Schematic

The laser tag vest and gun both share lots of the same components only differing in one or two components. The laser tag gun uses the TONYU DY-IR204T-E12 Infrared LED and the way this was connected was by connecting the anode to one of the GPIO pins on the ESP32, and connecting the cathode to a GND pin on the ESP. A resistor was also connected between the anode and the GPIO pin to limit the amount of current flowing through the LED to protect it. Using the formula R = (Vsource - VLED)/ILED and calculated the resistor value to be 21 ohms but chose a slightly higher value for extra safety (33 ohms). The UMW(Youtai Semiconductor Co., Ltd.) AMS1117-3.3 voltage regulator is what we went with. To connect the voltage regulator we started by connecting our power source to the input of the regulator. Then we place a 10uF capacitor close to the input pins to reduce noise and transient voltages.By placing a 22 µF capacitor close to the output pins of the AMS1117 we are able to maintain stable output voltage and minimize output noise and ripple. By placing a 22 µF capacitor close to the output pins of the AMS1117 we are able to maintain stable output voltage and minimize output noise and ripple. Then we connect the output pin of the AMS to the 3.3V input pin on our MCU, also connecting the ground pin to the GND pin on the MCU. For the MicroUSB port we went with the MOLEX 475900001 Micro-AB USB; to connect this we also needed a USB-to-UART bridge connector and we went with the WCH CH340G USB-to-UART connector. To connect everything together first the VBUS of the microUSB connects to the input of the voltage regulator and the VCC of the CH340G. The GND connects to the common ground, and the D+ and D- pins of the microUSB lines connect to the D+ and D- pins of the bridge connector. For the CH340 the VCC is connected to the 5V output. GND is again connected to common ground. TX and RX are connected to the opposite RX and TX of the ESP32 the RTS pin is connected through a 0.1 μF capacitor to one of the IO pins on the ESP32 (for automatic programming mode). For the RGB LED we went with the TOGIALED TJ-S3227SW1TCGLCCYRGB-A5 LED. In order to protect the channels that correspond to each channel of the RGB LED from too much current we add a resistor for each one. The formula is R = (Vsource - Vf)/I, for the red channel we got 65 ohms, for blue and green we got a resistor of 5 ohms. For connection the common anode on the LED is connected to the 3.3V power supply of the ESP32. Using the corresponding resistor value for each channel we connected each channel to its own GPIO pin on the ESP32. For the LCD display we chose the Newvisio N114-2413THBIG01-H13 The VCC on the LCD is connected to the 3.3V output of the ESP32 and the GND is connected to the common ground. The data connections include connecting the SCK to a clock-capable GPIO on the ESP32 in this case the GPIO18. MOSI pin is connected to GPIO 23 on the ESP32. Chip Select pin is connected to any GPIO pin on the ESP. Last, DC (Data/Command) is connected to a GPIO pin that can be controlled in software.

For the vest almost all these components are used but we get rid of the LCD display and the IR emitter. We replaced the IR emitter with the Vishay Intertech TSOP34838 IR receiver. Then to connect this we take the VCC pin of the receiver and connect it to the 3.3V supply from ESP32. GND is connected to common ground, and out is connected to a GPIO pin capable of input on ESP32. We also added the vibration motor to the vest schematic and for that we chose the KOTL Z3OC1T8219731. For this connection we utilize a MOSFET, connecting the source pin of the MOSFET to ground, the drain pin to the terminal of the vibration motor, and the gate pin to a GPIO with a 220-ohm resistor going through it (limits current flowing into gate and protects ESP32 GPIO). For the vibration motor we connect the other terminal to positive voltage supply.

Figure 6. Laser tag Vest Schematic

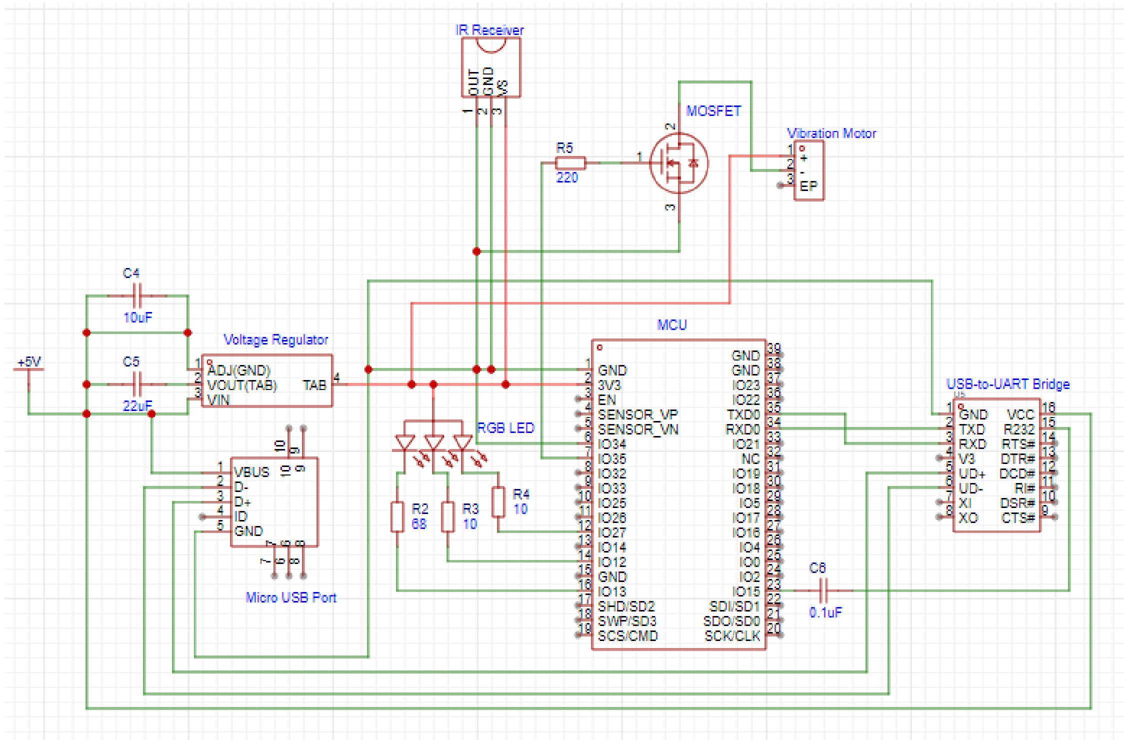
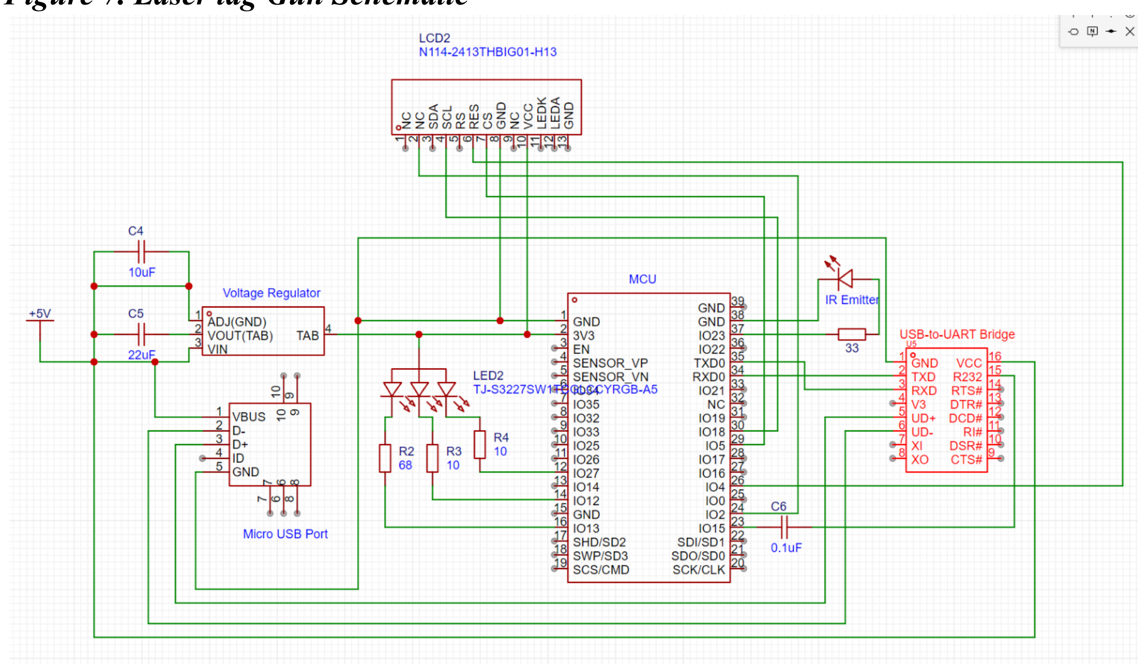


Figure 7. Laser tag Gun Schematic



6.2.4 PCB Layout

When thinking about which layout for our PCB would be the best for performance there were a couple things we had to consider. Obviously a compact and efficient use of space for our design would be optimal since there shouldn't be too much extra space on a PCB and the laser gun housing is compact as well. We also make sure to keep the signal integrity as strong as possible with our given design constraints. Each component chosen was made sure to support roughly the same operating temperature as a precaution and if needed we may decide to add thermal vias to the project for proper thermal management. Keeping components that are related in some way to each other close together to maximize efficiency was something we made sure to look out for. Designing our circuit to be easily manufacturable was key to our layout design process also. Testability was another huge consideration since we recognize that our first PCB will need revisions and it is crucial to give ourselves a way to troubleshoot properly. Lastly, the specific needs for the laser tag system were considered to make the system to our liking.

6.3 Embedded System Design

Embedded system design is a crucial part of the software design of the project and will greatly impact how our project functions as a whole. This embedded system design will give us the ability to run the entire project from the microcontroller in the embedded system. This gives us control over the entirety of the project's functions and lets us change, update, and read inputs from the environment. Having these controls over the project design is imperative to having a successful project and making sure that it runs smoothly.

The embedded system that is behind our project essentially is just a bunch of logic that turns specific inputs into distinct outputs. This logic written to the embedded system will be able to take inputs from multiple different things such as the infrared receiver, the trigger, the magazine, and the master terminal. These inputs are then registered in the internal system of the microcontroller and processed to produce outputs to the infrared emitter, LEDs, LCD, and haptic feedback motors. These inputs and outputs are all connected to the microcontroller through wiring or in our final design will be connected through the printed circuit board.

Embedded system development can be done in multiple ways and has numerous different approaches to accomplishing this goal. We are using the esp32 microcontroller which supports Arduino IDE using C/C++ languages and their functionality. Using C++ for our embedded software development gives us multiple features that will be helpful in our embedded system design. One of these is the use of object-oriented programming which is extremely important in software development. These object-oriented programming properties will give me many useful tools to use such as polymorphism, classes, objects, and inheritance.

Embedded system design is extremely important but how you design the embedded software is crucial to the project organization and functionality. Having well-thought-out and planned embedded system code can make the project much easier to understand, update, and debug. To accomplish this organization within our software we will be taking it one step at a time and dividing each section of our code into subsections to make it more structurally sound. One of the best tools we can use for our project that will help is object-oriented programming.

Object-oriented programming will be a huge part of how we organize our software which will make it much easier to add new features, debug, and increase readability. We intend to separate every section of the code into mini-sections and use objects to make it more organized. To do this we will utilize objects on things such as game modes, teams, players, phasor, vest, and much more. This will make a layer of objects that go inside the other such as a game mode with teams with players with a phasor and vest. Having this in our code will make it very easy to just create another version of the class or object which makes it very simple to add new features to our embedded design.

We intend to connect everything through one main runner which will first be prompted to get the game information to create a game object from our list of different game modes. The game mode class will have many different things connected to it depending on which one is connected but they will all have similarities such as needing team information before starting the game. Once the team information is inputted we will be able to create team objects which will all have team information such as team stats and player objects in it. These player objects will have all the player information and their stats and have objects for the vest and gun that will be used by the player. The vest and phasor objects will hold even more information and be the main input and output for the design.

The code itself inside most objects will be fairly simple and just hold information about that object but the phasor and vest design will be very different as it needs to connect to inputs and outputs. To do this we will have code in our design that will be able to read and write to inputs and outputs and then some login in between to decide what to output when we receive inputs.

6.4 Wireless Communication Design

In our wireless laser tag system, wireless communication plays a crucial role in facilitating interaction between all the peripherals such as the guns and vests. The ESP32 devkit, created by Espressif Systems, is used for prototyping and developing key parts of our project due to its excellent wireless communication capabilities.

6.4.1 Wi-Fi

The ESP32 supports 802.11 b/g/n Wi-Fi in the 2.4 GHz band and can reach speeds up to 159 Mbits/s. It supports various Wi-Fi modes, including Access Point (AP) and Station (STA), facilitating connectivity options. In AP mode, the ESP32 acts as a Wi-Fi network, allowing other devices to connect to it. This mode is useful when you want to establish a local network of devices. In STA mode, the ESP32 connects to an existing Wi-Fi network, similar to how a device such as a smartphone or laptop would. This mode is particularly useful when you want the ESP32 to communicate with other devices on the same network. The ESP32 can also operate in a mode where it can be an access point and a station at the same time, allowing it to act as a bridge between two networks.

Our laser tag system primarily uses Wi-Fi for communication to cover a large enough area in addition to speed and reliability. This allows all the peripherals like the guns and vests to work together simultaneously.

6.4.2 ESP-NOW

ESP-NOW is a connectionless communication protocol developed by Espressif. It's designed for efficient and low-latency communication between devices. ESP-NOW is ideal for scenarios where devices need to communicate directly with each other in a local network. It's a fast communication protocol that can be used to exchange small messages (up to 250 bytes) between ESP32 boards. It's particularly useful for applications where you need more than just a Wi-Fi connection, such as sensor networks and other applications.

In our project, ESP-NOW could be used for direct communication between the laser tag guns and vests, providing a fast and efficient method of transmitting data such as player hits, scores, and other game-related information.

6.5 Master Terminal Design

The Master Terminal is a central unit that controls all the game modes and monitors all the other chips in our wireless laser tag system. It is designed to provide a comprehensive overview of the game state, including player scores, game mode status, and device connectivity. The Master Terminal uses a web server hosted on an ESP32 chip. This web server acts as the central hub for all communication within the system. Each peripheral device (like the guns and vests) communicates with the Master Terminal via Wi-Fi, sending updates about their status and receiving instructions about the game mode or other operational parameters. The Master Terminal is responsible for managing the game modes. It sends instructions to all peripheral devices about the current game mode, ensuring that all devices are synchronized and operating under the same rules. The game mode can be changed through the Master Terminal's web interface, allowing for quick and easy adjustments to the game settings.

The Master Terminal continuously monitors the status of all peripheral devices. Each device sends periodic updates to the Master Terminal, including information about its battery level, operational status, and any errors or issues it might be experiencing. This allows for real-time monitoring and troubleshooting of the system, ensuring that any issues are quickly identified and addressed. The Master Terminal's web interface provides a user-friendly way to monitor and control the system. It displays real-time information about the game state and device status and allows for the game mode to be changed with just a few clicks. The web interface can be accessed from any device connected to the same network as the Master Terminal, providing flexibility and convenience.

Here are some of the key statistics and information the web server can display.

Game Stats:

- **Current Game Mode**: The current game mode that is being played. This could be ‘Free for All’, ‘Team Deathmatch’, ‘Capture the Flag’, etc.
- **Game Duration**: The length of the current game. This could be useful for tracking how long games typically last and if there are any issues causing games to end prematurely.
- **Player Scores**: The current scores of all players. This can help identify if scoring is working correctly and if there are any discrepancies.
- **Player Status**: The status of each player, such as ‘Active’, ‘Hit’, ‘Out’, etc. This can help identify issues with player status updates.

Device stats:

- **Device Health**: The battery level and operational status of each device. This can help identify if there are any devices that are not functioning correctly or are low on battery.
- **Signal Strength**: The signal strength of each device. This can help identify if there are any issues with wireless communication.
- **Error Logs**: Any errors or issues reported by the devices. This can be extremely useful for debugging as it can provide information about what went wrong and when.

Debugging:

- **Real-Time Updates**: The page updates in real-time, allowing you to monitor the game state and device status as they change. This can be particularly useful for identifying issues as they occur.
- **Manual Control**: The ability to manually change the game mode or device settings. This can be useful for testing how the system responds to different settings.
- **Error Alerts**: The page can display alerts when errors occur, helping the user quickly identify and address issues.

6.6 LCD Display Design

The LCD display is a very small component overall compared to the other different components required to make our project properly work. Unlike the other components, the project would be able to work properly without the LCD display working and its role in our project is just another extra component to make the project feel more complete as a final product. The LCD display will be a display that shows the current situation of the user playing the game and the overall situation of the game. This would allow the user to be able to keep up with the current situation of the game and not feel confused or lost when playing the game or using the product. The position that the LCD display screen will be on our gun will be on the upper part of the main housing unit so it is easily viewed by the user. We have decided that this position was the best for the design due to its ease of access to the user in a way that the user doesn’t have to do any extra work to view the screen as it is placed right in front of them.

The LCD display would then display the different statuses of the game such as the time left in the game, your current user's health, the amount of ammo or magazines left, and the overall score of the game. This will keep the user well informed of the situation around them. Also, there is a possibility of a button on the side of the gun that would change the look or the data displayed on the LCD display screen. Overall this component design will further enhance the user's experience when using the product.

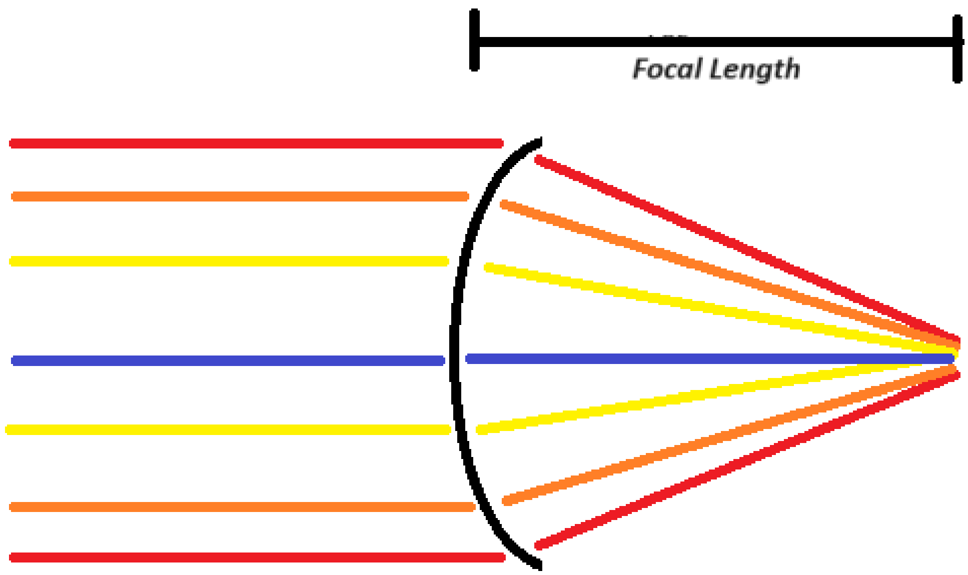
6.7 Optics Design

Optics are a huge part of our design and will make or break the playability of our entire game system. Optics are going to be one of the tougher challenges of this project as no team members have any experience in optics which will make this process very difficult. Although it may be hard with proper research about optics we have devised a plan that should work with good efficiency. To create a working optics design we will need to go through rigorous trial and error testing to make sure we achieve the best specifications in range and accuracy that we possibly can.

Having a fully functional optics design is needed because of how important they are to the functionality of our design if we were to just put an infrared emitter and sensor on our phasor and vest we would have absolutely no range because the emitter shoots unfocused infrared light in all directions which would make the game unplayable. Having a working optics design will make the infrared light from the emitter be focused on what is essentially a laser. This is still different from an actual laser as we are just using a lens to bend light into a thin beam.

To do this we will have our infrared emitter inside a tube and at the end of the tube a convex lens will be attached to focus the light from the emitter. These lenses have multiple different aspects to them that we have to understand to get the best optics for our design. One of the main aspects of lenses is the focal length this is essentially the distance at which the emitter has to be from the lens in order to acquire the most focused beam possible. This focal length is super important and can differ depending on the diameter, height, and curve of the lens. If the lens is too close to the emitter it would make the beam too wide and the light would not travel in a beam. If the lens is too far from the emitter it will cause the beam to be too tight and the light rays would then cross each other again and go out at a wide angle again. We need to find the perfect length to make the light go straight as shown in the figure below.

Figure 8. Lens Visual



7.0 Project Prototype Construction

Creating the first prototypes for the different components in this project allows us to quickly and simply demo the different components for the reviewers and our mentors to be able to review and analyze the different components used in the project. These prototypes stand as the very first step in the physical process in creating our project. We will use the information gathered when creating and testing these prototypes to better formulate a plan and overall design when creating the very first major prototype that would contain all the different parts and designs made during the process. This section contains all the major prototype parts such as the gun, vest, 3D printed housing, PCB, and component prototypes. And in the very end, contains the first simple prototype that represents a very simple demo of what we plan the gun to do.

7.1 3D Design Prototype

The 3D design prototypes that will be created during the first senior design semester will be created using the program Onshape. These designs will contain the different components in this project. The 3D designs are just simple 3D Cad models that represents the different housing units for each components. All these models can be translated into STL files that could be utilized by a 3D printer to create a 3D printed plastic model or unit that would be used for our project. The material and 3D printer used to create these designs were stated before in this paper and this would be the major way that we will use to create the different part that would house the different components in this project.

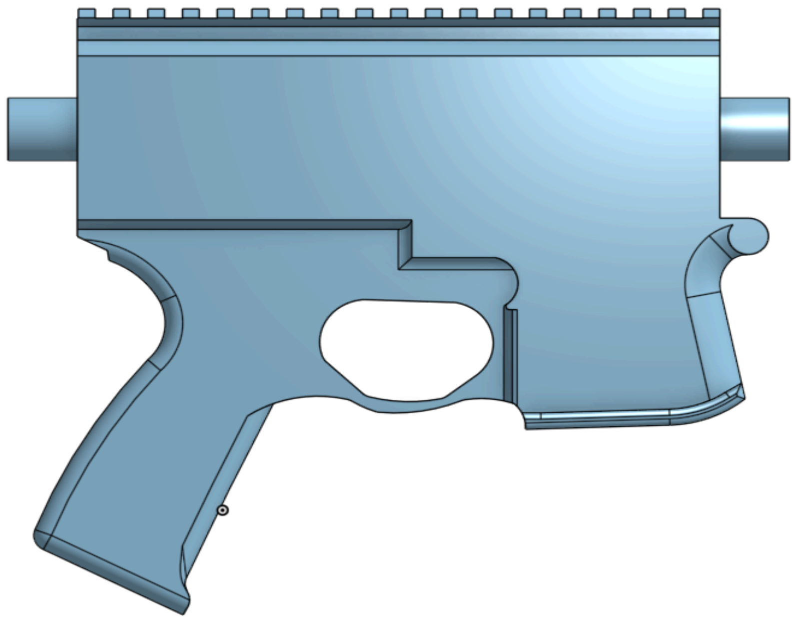
7.1.1 Gun and Vest Explained

Within this section, we will discuss and present the prototype designs for physical housing units for the gun and also the housing unit for the different sensors on the vest. Each one of these designs is the starting prototype and is expected to be changed or adjusted based on the different issues or complications that we experience when making our product. The 3D gun models also contain the different attachments that will be added to the gun and also include possible areas where more attachments can be added to the final product. Some of these models are too large to print as one whole model so possible post-modeling work is necessary to properly cut the model into printable parts for the user to be able to print the 3D CAD model.

7.1.2 Gun Design

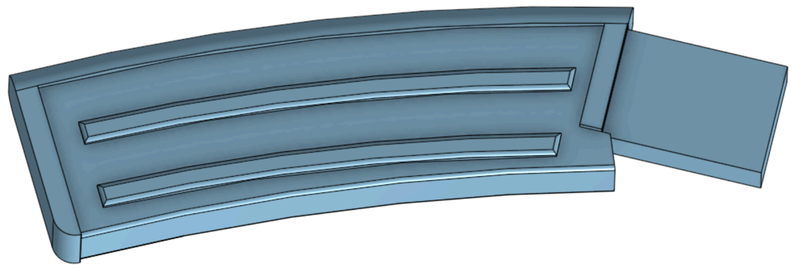
The gun model itself contains many different components that will interact with each other to create a complete gun. These parts will contain the main gun housing, shoulder stock, barrel shroud, sights, trigger system, and magazine. Some of these parts will contain different components within the model itself while others will play the role of an accessory or attachment that makes the overall system more immersive and unique. Some such attachments that will act as extra attachments are components such as the shoulder stock and sights. But components such as the main housing, magazine, trigger system, and barrel shroud will contain important components that will influence the overall system. Many of the extra components will contain modular attachments that will allow the user to easily adjust and change out certain attachments with other possible attachments developed in the future.

Figure 9. First Main House Prototype



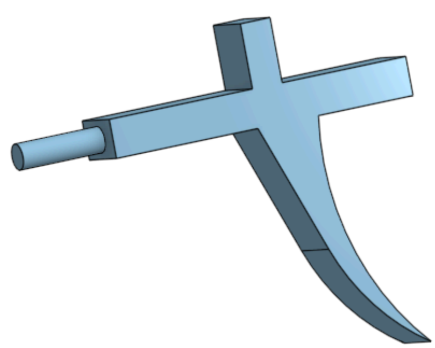
The initial prototype of the laser gun project can be seen in the image above which shows the starting point and direction we will proceed with for the main housing unit for the laser gun project. This main housing unit serves as the main central hub for containing a majority of the essential elements needed for the laser gun to properly operate as designed. The design for the main housing unit was created with the intention of creating a large enclosed space to contain ample room for critical components such as the main Printed Circuit Board or PCB, and various other components such as buttons and switches for the user to reload and shoot the laser gun. Moreover, the design of the main housing unit contains modular options to possibly add more attachments to the unit. One example of the modular option is the circular ends at the front and back of the gun. These points will facilitate barrel and stock attachments to the main housing unit. The modular mechanism for these parts is still being tested and will further be improved throughout Senior Design 2. Also, the Picatinny rail above is a very common mechanism used even in real-life firearms. Many real-life firearm attachments use this mechanism and by including the Picatinny system in our own CAD design we will allow the usage of external attachments owned by the users and allow external compatibility with other products.

Figure 10. First Magazine Prototype



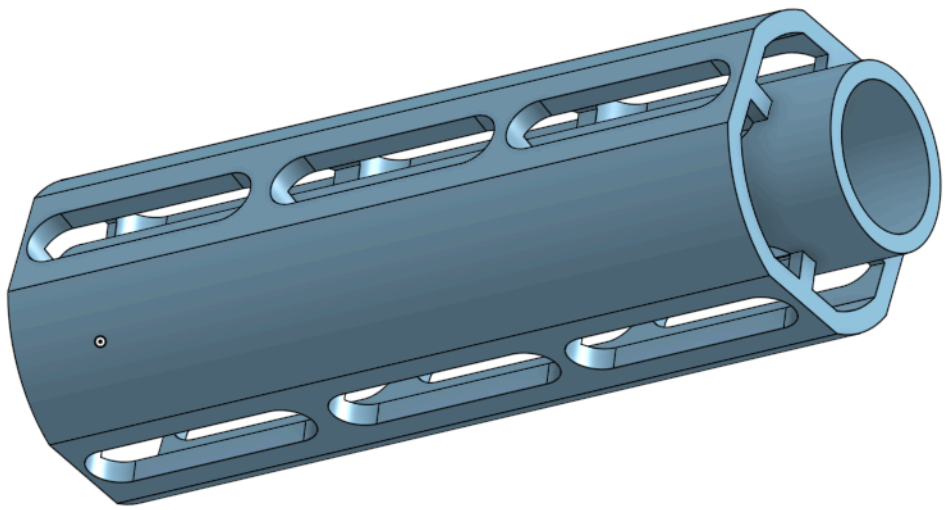
The magazine plays a major role in real-life firearms, without the magazine you would not be able to reload the gun and allow the user to continue to shoot the firearm. In our project, the magazine also plays a similar role to real-life firearms, to properly reload the laser gun you would need to take out the magazine and push it back into the gun activating a button on the top of the slot that would active the reloading portion of the code allowing the user to continue shooting. This action is to replicate the movement and feel that the user would usually experience whenever they had to reload a real firearm. The ability to replace or change magazines could also add the possibility of holding different styles of magazines such as a drum magazine or an extended magazine that creates a different look and feel for the gun. In the prototype design of the magazine, we simply created the basic curved magazine for a submachine gun with very little design to enhance the feel and look of the gun. Also, the grips on the side of the magazine allow a better grip on the magazine whenever using it.

Figure 11. First Trigger Prototype



The design of the trigger mechanism is highly important for the overall laser gun process. If the trigger mechanism fails to activate the shooting mechanism of the laser gun then the laser gun would not be able to function the way it is expected to when firing. Another aspect of the trigger mechanism that is important is that it would properly reset to its original position after pushing down the trigger. This will be achieved by having a spring push back the trigger when the user lets go of the trigger. The spring will be held on by the circular extrusion in the back of the trigger.

Figure 12. First Barrel Prototype



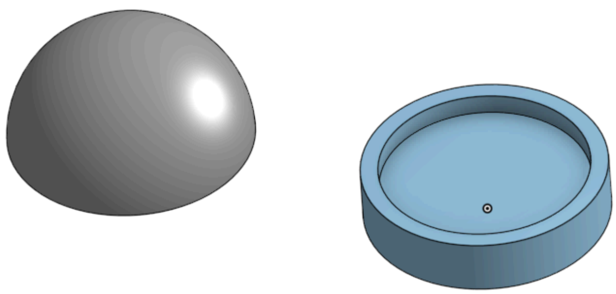
The barrel shroud is a very important piece and component of any real firearm in the real world. This component is visually one of the most memorable pieces of a gun and without a proper barrel, any attempt to make a realistic-looking firearm would fail. For our project, the barrel will possibly contain the infrared red emitter and lens to make the infrared emitter have a more focused beam for the vest receiver to receive. For this first prototype, the outside of the barrel is smooth and doesn't contain many different possible attachments to the barrel.

In the end, the last component that needs to be 3D modeled is the stock of the gun, this component isn’t very important and is mostly meant for cosmetic reasons. This part of the gun will most likely be developed and printed as the very last step of the project due to not having any major parts in the overall system for the laser gun. The stock will share the same modular system as the barrel and will be placed at the back of the main housing unit.

7.1.3 Vest Design

The overall vest design is fairly important for the immersion of the game and the product we are trying to create. The vest will contain the main PCB meant to contain and receive all the information gathered by the different sensors at different points of the vest. It will also output the output voltage needed to light up LEDs or send out important information using Bluetooth or wifi to other users. The main PCB will be held in a very simple but small box on the chest of the vest and cables will stretch to the other sensors surrounding each major part of your upper body including the chest, back, left, and right shoulders. The design of the container holding the sensors is a very typical dome-shaped container, this container will boast a clear acrylic dome lid that will help infrared light pass through but also contain and protect any of the sensors. Multiple sensors are expected to be held in the container to gather and be able to receive in a wide range of degrees. LED lights will also be within these dome containers to represent where the user gets shot whenever the sensors get infrared lights as input.

Figure 13. First Dome Sensor Container Prototype



7.2 PCB Prototype

The PCB prototype for our project was created with the EasyEDA PCB design software. All parts used for the prototype were found using LCSC Electronics found online on lcsc.com. Something that made the PCB design process super-efficient and simple was the accessibility of all lcsc components directly integrated with the parts tool on the EasyEDA software. When designing the PCB prototype, I made sure to keep the size to be less than 100 x 50 pages to make sure it fit into the enclosure. We plan on having the LCD display face the user so that the player can receive live feedback while they are playing. We plan to place the IR emitter as close as possible to the barrel of the gun and make the proper adjustments to make that happen on the PCB. The placement of the microUSB is at the bottom of the PCB and makes it very simple to access, to program the ESP-32 MCU. Another big consideration was the placement of the battery source, we made sure to place the battery holder close to the mcu and near the bottom of the gun for easy replacement. We also decided as a team that we wanted to add extra buttons to be able to add different features in the future if we wanted to. The PCB for the vest is very similar to that of the gun but there are some differences. We had to place the vibration motors in an optimal place that would provide the user with the best experience, making sure it was placed somewhere that isn’t too bothersome but also can provide an enjoyable experience. The IR receiver we also plan to place in an optimal place that has a clear visual for reception. Everything else in the PCB is pretty much set up the same for easy accessibility.

Figure 14. Laser tag Gun PCB

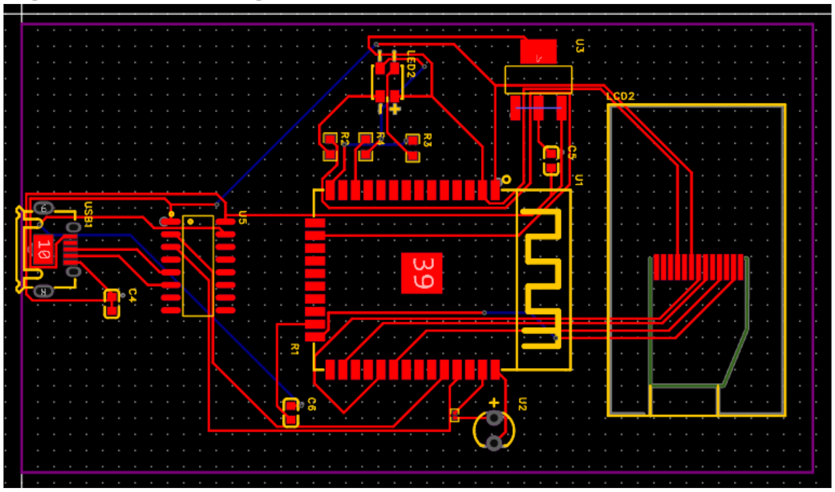
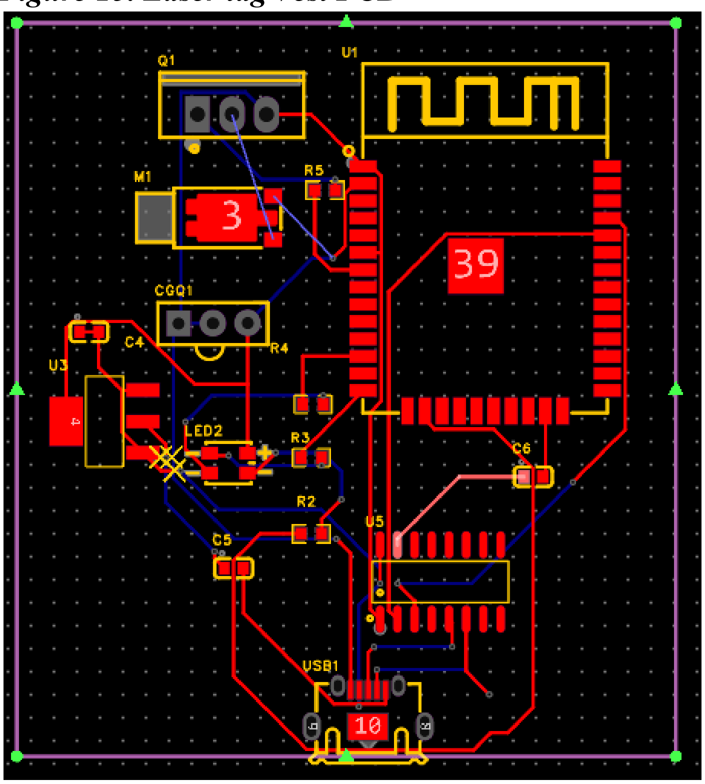


Figure 15. Laser tag Vest PCB



7.3 IR Emitter/Receiver Prototype

The infrared emitter and infrared receivers are some of the first components that we tested and evaluated when designing and creating our prototypes. These two components have a very important role in our project since without these two components, the concepts and designs that we as a group have come up with would not be realistic. The testing prototypes for these components are very simple and would just contain the most simple parts to test the emitter and receiver and make sure that the theories behind our project are realistic and could very much lead to the production of our final prototype. For these prototypes, we also used a developer board to simplify the PCB creation for these prototypes and decrease the amount of unnecessary effort and time that would be needed to be created to create a testing prototype for the infrared emitter and receiver. The developer board that we have utilized for these two prototypes is the Elegoo R3 Uno due to its small size and ease of use, also the developer board itself utilizes the Arduino IDE which would be similar to the MCU chip that we will use in the final product. So in the end, the code for the prototype could be utilized for the testing and creation of the final product.

The infrared emitter prototype can be simply described as a prototype that emits infrared light after the user or tester pushes the button that activates the light. For the first prototype, all the components would be placed on a simple breadboard to contain and connect all the components. Then these components would be attached to the developer board to output voltages and receive any information achieved by the infrared emitter. This includes a button where we need to establish a pull-down resistor to make the button output zero voltage to the MCU developer board. Hence whenever you push the button the 3.3 volts going into the button can then be directed to the developer board which senses that the user pushes down on the button. This will then send a voltage to the infrared emitter which there would need to also contain a voltage divider to make sure that the infrared emitter does not burn out completely during use. This is a result of the fact that the voltage spec for the infrared diode is around 1.7 volts while the lowest output from the Elegoo R3 Uno is 3.3 volts. But once the infrared emitter diode receives the voltage then an infrared light is outputted from the overall prototype and it is now the job of the receiver prototype to receive the infrared light.

The infrared receiver prototype is also a fairly simple prototype design where the goal is just to simply sense and receive an infrared light and have some sort of reaction/output to show that the prototype has sensed an infrared light. The breadboard prototype contains a simple infrared receiver diode, RGB LEDs, and a simple motor that demonstrates a possible haptic feedback motor. The hardware flow for this prototype is that the infrared receiver senses the infrared light that was output by the infrared emitter prototype. This infrared receiver diode has a pull-down resistor which would make the output voltage zero whenever the infrared receiver diode doesn't sense any sort of infrared light. But once it does receive an infrared light, it would send a voltage to the MCU developer board which the program would sense that the receiver diode has sensed an outside source of infrared light. Once it senses the infrared light then the MCU developer board will output a voltage of 3.3 volts to the motor and LED lights to show that the prototype successfully received the infrared light. These two components represent the different visual indications that would be on the vest.

Overall these two prototypes are simply demo tests for the components to accomplish the theory that is behind our project idea. We are mainly using the prototype to test out the components and gather a general idea and knowledge on how to utilize the components and ways to implement them in our final design. These prototypes are simply temporary to test the components and have very little connection to the final design that we will create for the project. Almost none of the creation and design for these two prototypes will be shown in the final schematic.

7.4 Wireless Communication Prototype

When prototyping and testing, the primary goal is to assess the performance, usability, and capabilities of the components we plan on using. One of the main aspects that facilitates communication between all the peripherals in the laser tag system. All the peripherals like the guns and vest must be able to work together simultaneously and further trickle down to the sensors, LEDs, and haptic feedback. The ESP32 was chosen because of its great wireless communication capabilities. Therefore various testing was done using VS code and the platformIO extension to create an environment where we can encompass all the different "sketches" or code snippets we plan to use.

When developing, prototyping, and testing with the ESP32 development kit, the combination of Visual Studio Code (VSCode), PlatformIO, and GitHub can be incredibly beneficial. VSCode, a powerful source code editor, offers features like IntelliSense for smart completions based on variable types, function definitions, imported modules, and built-in debugging tools. It also provides seamless Git integration, allowing us to commit, pull, and push our code changes to remote repositories directly from the editor. PlatformIO, an open-source ecosystem for embedded development, complements this by providing a cross-platform code builder and library manager. Its integration with VSCode provides a robust environment for development along with its automatic device detection and COM integration. Together, these tools provide a comprehensive, efficient, and collaborative development environment. They streamline the process of writing, testing, and improving code for the ESP32, making it easier to prototype wireless communication applications and iterate on them based on test results. These powerful combinations significantly boost our productivity and enhance the quality of our project.

The ESP32 devkit created by Espressif Systems was used for prototyping and developing key parts for our project. The chip supports an array of capabilities for wireless communication and protocols such as Wifi, Bluetooth, Bluetooth Low Energy(BLE), ESP-NOW, LoRa, MQTT, and GSM/LTE. Each comes with its own benefits and drawbacks so we must choose the appropriate protocols that satisfy the requirements of our project. Popular Laser Tag systems communications are primarily carried and developed using WiFi in order to cover a large enough area in addition to speed and reliability.

7.4.1 Wi-Fi Prototype

The first thing that is necessary to wirelessly communicate between the ESP32 chips is the MAC address. Each EPS32 has its own MAC address making them distinguishable and is the first step towards making them connect to each other. The WiFi library is the primary library used to accomplish this. After uploading the code using the platform io automatic device detector and automatic COM after it is written to the flash, I got the MAC address of the 2 devices on hand and labeled them as so. Next up is utilizing the WiFi capabilities of the devices and creating a scanner sketch. The WiFi scan uses the WiFi library as before, the setup consists of starting a serial for debugging and log purposes. In the loop, I use green and red LEDs with 220 ohms resistors for protection to indicate whether or not the Wi-Fi signal has been detected. It would light the green LED when it successfully found at least one Wi-Fi signal in the surroundings and light up red when it hasn't found any. In the Serial COM monitor, I print the available networks as well as their level of security whether they were open or encrypted with a password. This could be particularly useful when the master controls all the chips during the game to make sure they are all connected to the same network and receiving information.

One of the strong suits of the ESP32 is its ability to create a web server. This can be done in both Access Point (SAP) mode and STA mode. Creating a web server on the ESP32 opens up a multitude of possibilities for controlling the device remotely. This is particularly useful in applications where you might want to control or monitor your ESP32 device from anywhere in the world. By setting up the ESP32 as a web server, I can design a web page that sends commands to the ESP32. These commands could be used to control various aspects of the ESP32's functionality, such as toggling GPIO pins, reading sensor data, or even adjusting system settings. For instance, I could create a simple HTML interface with buttons that, when clicked, send HTTP GET requests to the ESP32. The ESP32, running a web server, would listen for these requests and perform actions based on the specific command received. This could be used to turn an LED on or off, adjust the speed of a motor, or read data from a sensor. Furthermore, by leveraging the Wi-Fi capabilities of the ESP32, the web server is accessible from any device connected to the same network as the ESP32.

Creating a web server on the ESP32 is relatively straightforward, with the libraries included by Arduino and Esspresif. Using the wifiSAP and WiFi library I'm able to configure the ESP32 to create a web server on my WiFi. The website consists of simple HTML code containing two buttons that control the state of the GPIO pins that the red and green LEDs are connected to. It listens for clients and reads their inputs continuously in the loop. If a newline character is received, it checks if the current line is blank, indicating the end of the client's HTTP request. It then sends an HTTP response with headers and a content type of text/html. If the HTTP GET request is for turning on or off the LEDs connected to GPIO pins 16 or 17, it changes the state of the corresponding pin using digitalWrite(). It sends an HTML response that allows the client to control the LED state. The HTML includes buttons for turning each LED on or off. When a button is clicked. This code effectively allows the user to control the state of two LEDs connected to your ESP32 device from any device connected to the same network, by simply clicking buttons on a web page served by the ESP32, it sends an HTTP GET request to turn the corresponding LED on or off.

This is powerful and can be used in a multitude of ways in our project. It can be used as a way to configure many settings from, game modes, players' health, types of guns, and more. It can also be used as a live feed into the current game, keeping track of each player's accuracy, kills, and death. Overall, this is a way to make an engaging platform easy for users to use.

7.4.2 ESP-NOW Communication Prototype

ESP-NOW is a connectionless communication protocol developed by Espressif, the company behind the ESP32 microcontroller. It’s designed for efficient and low-latency communication between devices. Here are some key features and details about ESP-NOW.

- **Short Packet Transmission**: ESP-NOW features short packet transmission. This protocol enables multiple devices to talk to each other without using Wi-Fi23.
- **Payload Size**: It can be used to exchange small messages (up to 250 bytes) between ESP32 boards.
- **Versatility**: ESP-NOW is very versatile and you can have one-way or two-way communication in different setups.
- **Persistent Connection**: After pairing a device with each other, the connection is persistent. In other words, if suddenly one of your boards loses power or resets, when it restarts, it will automatically connect to its peer to continue the communication.
- **Encryption**: ESP-NOW supports encrypted and unencrypted unicast communication.
- **Limitations**: There are limitations on the number of encrypted peers. 10 encrypted peers at the most are supported in Station mode; 6 at the most in SoftAP or SoftAP + Station mode

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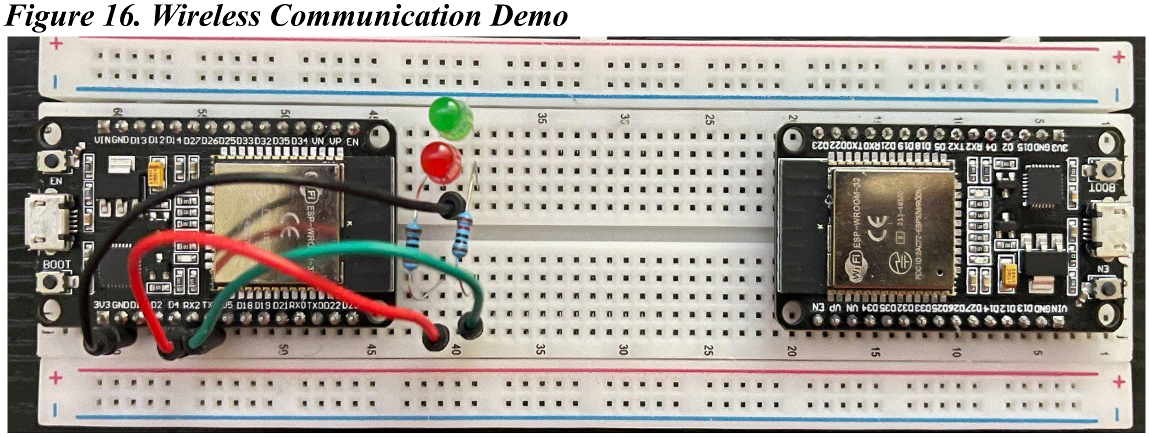
- **Limitations**: There are limitations on the number of encrypted peers. 10 encrypted peers at the most are supported in Station mode; 6 at the most in SoftAP or SoftAP + Station mode

ESP-NOW is ideal for scenarios where devices need to communicate directly with each other in a local network. It’s a fast communication protocol that can be used to exchange small messages between ESP32 boards. It’s particularly useful for applications where you need more than just a Wi-Fi connection, such as sensor networks and other applications.

This is done by importing the esp_now and WiFi libraries as needed. To establish communication via ESP-NOW the MAC address is needed for the device we plan to establish communication with. This is where the earlier step to get each device's MAC address comes in handy. First with the sender, having gotten those addresses, we create a message structure to send, for I plan to send a simple button state integer. An esp_now_peer_info_t object named peerInfo is defined. This structure is used to add a peer. The onDataSent function is the callback function that gets called when data is sent. It prints whether the delivery was successful or not. A setupEspNowSender function initializes the ESP-NOW, registers the callback function, sets up the peer information, and adds the peer. A loopEspNowSender function is continuously running. It reads the state of the button, updates the button_value in the myData structure accordingly, and sends this data to the receiver. It prints whether or not the data is sent successfully or not.

The receiver side is very simple, it doesn't require the setup that the sender needs. We use the same libraries and define the LED pins. Next, we must define a structure for the message being received, this closely resembles the structure defined by the sender. The OnDataRecv function is used as a callback function that gets called when data is received. It copies the received data into the my_data structure and prints the number of bytes received and the value of the button. The setup function consists of initializing the ESP-NOW and setting up the LED pin as output. The loop function is used to continuously check the button state in the structure that is being received, it turns on the LED if it reads 0 and turns it off if it reads 1. This might seem backward but the ESP32 by default buttons on the devkit are set as active low, this means that the digital reading from the button pin is LOW when the button is pressed, and HIGH when it is not pressed.

Figure 16. Wireless Communication Demo



7.5 First Prototype

In our first prototype, our goal was to include all of the parts that we have been testing with and combine them into one breadboard system that shows each part working together. We also wanted to not only include each part working but also some examples of software concepts that will be used in our phasor design. This design will show the main function of the laser tag project including using infrared emitters and receivers, LEDs, Buttons, LCD, and Haptic feedback motors. These will be the main inputs and outputs to our first design and will make this prototype a great starting point for a fully functional laser tag system

The first part of this project will come from our infrared emitter and receiver prototype to show the function of these components. These emitters that we are using for our prototype are just diodes with two ends the longer end is the anode or positive end and the shorter end is the cathode on the negative end. We have placed these diodes on our breadboard with a few inches in between them to make it easier to test if it's working. These will have wires and resistors connecting them to the esp32 to be able to read and write to them.

Connecting these wires was not too hard for the emitter and receiver because of our previous testing using them but here is how we did it and you can follow each step by looking at the table below. To do this will have an emitter that will have the cathode connected to the ground (white wire) and the anode to a GPIO pin on the esp32 (green wire) that when signaling an output in the code will turn the emitter on. The other aspect is the infrared receiver which will have the cathode connected to the 3.3V output from the esp32 (orange wire) and the anode connected to two things a GPIO pin on the esp32 (green wire) and a pull-down resistor that goes to ground. This set up will allow us to read and write to the emitter and receiver.

Connected directly with the logic of the emitter and receiver are a few other parts such as LEDs and a haptic feedback motor. Right next to the infrared emitter is a red led diode which we are using to visualize when the infrared emitter is on since we cannot see infrared light. It has its cathode connected to the same as the infrared emitter going to the ground (white wire) and the anode connecting to a GPIO pin on the esp32 (purple wire). The logic for this is the exact same as the infrared emitter because we want them both to turn on at the same time. On the emitter side of the logic in order to make sure that we are reading the input correctly we have two things the haptic motor and the led on the esp32. We use this to show when the emitter senses light which in a game of laser tag will trigger the haptic motors on the vest and we use the led so that we can see when the motor is unplugged due to its annoyance of it vibrating on the breadboard. The haptic motor is very simple and easy to use as it has one end connected to a GPIO pin on the esp32 (purple wire) and the other to the ground.

To complete the shooting logic that tells the emitter when to turn on we have two button inputs. Each button has its own purpose the left one is to turn on the infrared emitter or fire a laser and the right one is to reload to gain more ammo. These buttons connect to the GPIO pins on the esp32 (blue wires) and to the ground (grey and brown wires). This allows us to take the input from the buttons and when the trigger button is pressed it will turn on the emitter until we run out of ammo and then the reload button will refill the ammo. This will give us a more realistic shooting aspect to our demo as you will need to reload after shooting just like a real gun.

7.6 Full Phasor Prototype

The full phasor prototype is very different from the first prototype but also very similar in a lot of ways. This design instead of being an overall design like the first prototype is just a phasor design with phasor functions. First off it is similar because it has some of the same features such as a trigger input, magazine input, and an emitter output. It's also different as it does not have an LCD connected to it, a haptic motor, or an infrared receiver. Not only does it have some features from the first prototype it also has some new features such as fitting inside a gun model, having optics, and being battery-powered. These features make it a great first prototype to base our project on and improve on this design.

We started this design with a toy battery-powered Nerf gun one of our team members had and was not using and we decided this would be great to store a demo inside. We opened the Nerf gun up and it had some pretty interesting things first it had some wires that connected through the trigger and the magazine and led to a motor in the front of the gun. This motor was to shoot bullets out and was only given a voltage when the trigger was pressed and the magazine was in. We had no use for the motor so we took it out and with some wiring and soldering we connected the trigger and magazine buttons separately to make them not connected and have their own voltage when pressed. After taking out some other parts that weren't needed and clearing some room for the esp32 we had a gun that could house the parts we needed for the demo.

Next, we had the housing down for our prototype we needed to connect the esp to the battery source to power the esp32 for our design. Luckily for us, the battery holder that is built into the Nerf gun worked perfectly and did not need to be fixed or changed. This was great because it fits 4 AA batteries which is the same we intend to implement to our design because it gives a perfect voltage of just over 5V. This is what we use to power our gun and we used some wires and soldering to connect the 5V to the Vin pin on our ESP32.

After this, the gun is connected and powering the ESP32 we need to be able to read inputs from the trigger and the magazine. To do this we had to understand how the trigger and magazine buttons work so using some testing we found out that once the buttons are pressed the voltage goes from 0 to 5V from the battery. To use this voltage as an input directly to our ESP GPIO pins is not safe for the board so we must take the voltage down to the safe 3.3V that the GPIO pins can take in. To do this we used a simple voltage divider circuit using two resistors one being twice the resistance of the other and connecting to the ground that would bring the voltage to 3.3V from a node in the middle. We made this by connecting both circuits using wiring, soldering, and other techniques and connected the 3.3V to the GPIO pins on the esp32. After that, we were able to read input from both the trigger and the magazine.

Finishing our design we have to connect the laser technology to finish our design. To attach the infrared emitter to the esp we used wires that ran through the gun housing. This was connected to our optics prototype which was just a lens taped onto the end of the barrel and an LED placed at the focal point to make the beam the most focused it could possibly be. After connecting the wiring to the infrared LED and setting up the lens we will have a perfectly functioning laser tag phasor.

Figure 17. Phasor Prototype (External)

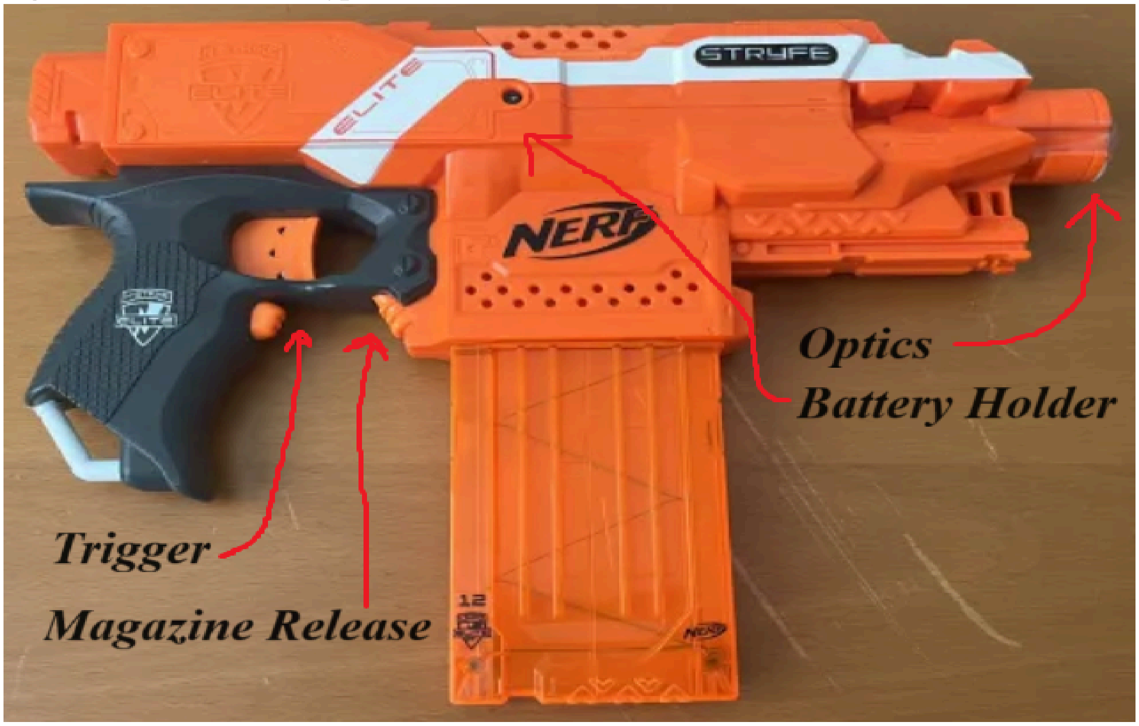
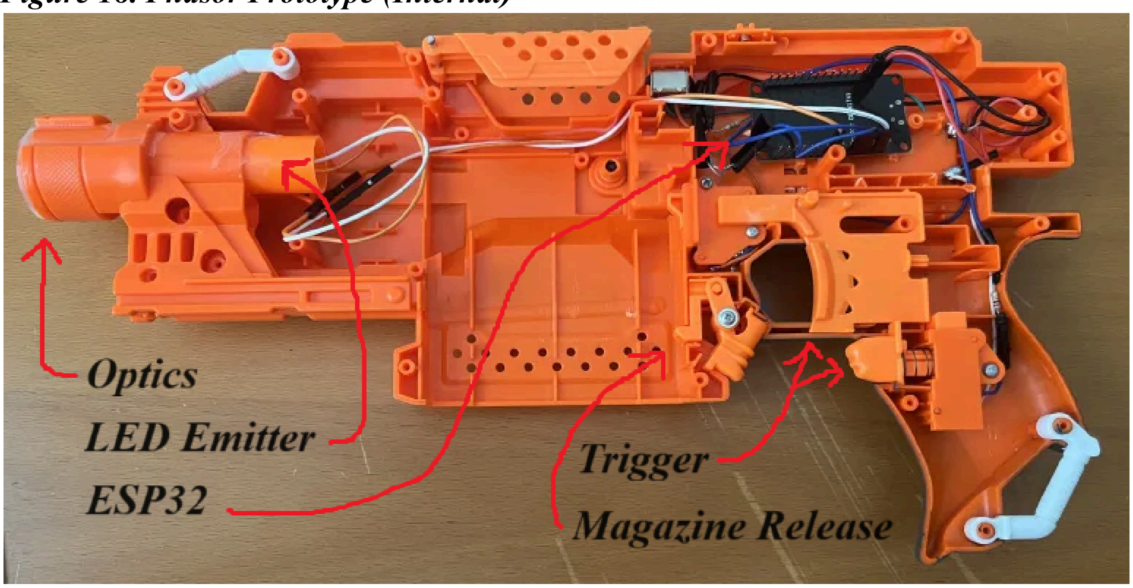


Figure 18. Phasor Prototype (Internal)



8.0 Project Testing and Evaluation Plan

It is very important to do basic testing and create simple prototypes for each component that would be later utilized or researched in this project. This allows the group to be able to properly see each component working with a simple breadboard prototype and also how it could be later applied to the PCB in the final prototype. This is to prevent possible situations where a component does not function the way that we have researched as a group and prevent the need for time to find another replacement part. This also possibly allows sponsors and other groups to understand the realism behind the project and whether the project itself is viable and able to be completed within the deadline. After completing these tests, we will also be able to complete a plan that would guide the overall project and set deadlines by which basic prototypes would be completed until we create the final prototype that will consist of the final project.

8.1 IR Emitter and Receiver Testing

The basic prototype for the infrared emitter and infrared receiver allows the group to better understand the utilization and process in which we will be able to detect infrared light and also emit infrared light in our project. Due to the infrared emitter and receiver being a major part of the project, we created a basic prototype that would emit infrared light when a button is pushed and light up an LED when the receiver is able to sense the infrared light. For both the receiver and emitter we used a diode for the components which consisted of a basic power and ground pins that would be utilized to use the components. When testing we realized the short distance in which the receiver would be able to detect and notice the infrared light. This realization led to the group adding lenses for the infrared emitter to extend the distances in which the receiver would be able to sense the infrared light. Overall this prototype allowed us to test the basic and simple versions of emitting and receiving infrared light.

8.2 Wireless communication Testing

For ESP-NOW, we tested the communication between two ESP32 devices. We used the MAC addresses of the devices to establish a connection. We created a simple message structure to send a button state integer from one device (the sender) to another (the receiver).

The sender reads the state of the button, updates the button_value in the data structure accordingly, and sends this data to the receiver. The receiver, on the other hand, continuously checks the button state in the structure that is being received. It turns on an LED if it reads 0 and turns it off if it reads 1. This might seem backward but the ESP32 by default buttons on the devkit are set as active low, meaning that the digital reading from the button pin is LOW when the button is pressed, and HIGH when it is not pressed. This test effectively allowed us to control the state of an LED connected to one ESP32 device from another device, demonstrating the successful communication between the two devices using ESP-NOW.

For the web server, we used the Wi-Fi capabilities of the ESP32 to create a web server accessible from any device connected to the same network as the ESP32. We designed a simple HTML interface with buttons that, when clicked, send HTTP GET requests to the ESP32. The ESP32, running a web server, listens for these requests and performs actions based on the specific command received.

We tested this setup by connecting various devices to the same network as the ESP32 and interacting with the web page served by the ESP32. We were able to successfully control the state of two LEDs connected to the ESP32 device from any device connected to the same network, by simply clicking buttons on the web page. This demonstrated the successful operation of the web server and its ability to receive and process HTTP GET requests. These tests were crucial in validating the functionality of our wireless communication system and helped us identify and rectify any issues early in the development process. They ensured that our system was ready for integration into the larger laser tag system.

8.3 Optics Testing

Optics testing is a huge part of our project as without proper working optics we will not have any range or accuracy on our gun. Our optics all revolve around the convex lenses that will guide our infrared emitter into a condensed beam. To test with the optics we bought six different lenses to test with three different types of lenses. Our goal is to figure out which lens works the best and how to set it up to get the best results for our phasor design.

To do the testing the easiest way was to test with a red LED emitter instead of using infrared this is because we can see the light coming from it unlike infrared which is invisible to the naked eye. To test the optics I had the lens taped to the end of the barrel and inside the barrel, I had a pipe with the red LED in it connected which allowed me to move it in the barrel. Given the LED was able to move I was able to go forward and backward till I found the focal point of the lens where the light is focused into the lens at the proper angle to be directed out in a beam. To test this I just kept moving the tube until I found the sweet spot and then taped it down to keep it in place.

8.4 Hardware Testing

Hardware testing is important in this project to make sure all of the hardware aspects of this design are functioning properly. The hardware testing that this project encompassed was very simple but very important. Of the hardware testing that we did, it was usually for two reasons. One of them was to test if the hardware components were all working properly by testing them through hardware tactics. The other was to make sure that certain parts of the design and hardware parts were working together properly and giving the correct values that they should be.

Testing the hardware components was fairly simple and did not require too much work. To test the led diode we can simply connect a small voltage across it and it will light up. The infrared LED works exactly the same but we are unable to see it so it has little purpose when testing. The haptic feedback is the exact same too just connect a voltage across it and it will vibrate. This just shows how some parts can be tested using hardware tools and how it's done.

The main part of hardware testing that was apparent was when building our final prototype. Using the multimeter in the senior design lab was crucial to knowing the voltage of certain parts of the prototype. This is because since we are powering the entire system using AA batteries we need to be able to see the voltage that it's giving before we can plug it into the esp32. We used the multimeter to test the power coming from the batteries to make sure it was 5.3V before plugging it into the ESP32. We also tested multiple other parts in our system as we needed to know if things were actually working and providing the correct voltage.

Apart from just the battery output voltage some of the other things we tested were the buttons and making sure the voltage divider circuits were functioning properly. To test the buttons on the trigger and magazine was fairly simple we just took the output wire and put the positive end of the multimeter to it and the negative to the ground. This means that when it wasn't pressed it gave 0V but when it was pressed the circuit was connected and the 5V battery positive was connected to the output wire. After we got the 5V from the button we needed to turn it down to 3.3V to make it safe for the esp GPIO pins to do this we used a simple voltage divider circuit. To test if the voltage was correct we put the positive end of the multimeter between the two resistors and the negative to ground and we got 3.3V.

Using hardware testing was super helpful for our project and was crucial to building the final prototype. This helped because we were able to also test to make sure that everything was on and that we weren't missing things. Multiple times we either did or didn't get an input into the esp32 and we made sure what was wrong and used the multimeter to make sure the voltage was what we expected it to be. In some cases the voltage wasn't what we expected. We saved a lot of time finding the problem early instead of wasting our time thinking our code was wrong.

8.5 Software Testing

Software testing was a big part of our project and took up a large amount of our time building the prototype. Most of the issues that we faced when building our prototype were in software testing and something not working. Our team has software experience but sometimes things just don't work how you expect them to and you have to adjust. Most of the software testing we did using the esp32 was just to make sure we could connect different parts to the microcontroller. We had to make sure each input and output we would use would function and work correctly before we could combine them all into one design.

Most of our software testing revolved around checking values from inputs and outputs. The biggest thing that helped us when software testing was being able to see what was being done at each moment in time using the serial print feature. The serial print feature just prints to the computer whatever you want which could be just a word saying test to see what part of the code you are in which is very useful to see if the code is skipping over or staying in certain parts. Serial print can also let you see a value which allowed us to see what part wasn't working and outputting the values it should be. This helped essentially debug the parts of the code that wasn't inputting and outputting correctly. The other part of the code that isn't just input and output is the logic to test this we also used serial print to make sure every step was being done correctly.

Software testing outputs was fairly easy but a big aspect of our project as there are a lot of outputs that we need to worry about. For most of the parts we just had to make sure that everything we were doing was being done correctly to test that things were working. This was not easy if you are not paying attention you may miss something like a mistake in your logic or a GPIO pin being the wrong number. Something even as small as that can be a huge issue when testing outputs.

Testing inputs are completely different and are way more prone to failing whether that be from faulty code or the connection is not set up correctly. Either way, it can be tricky but using serial print makes things a lot easier and allows you to see what the inputs are actually receiving. This also lets us test things such as the range of the infrared receiver the closer it is the higher the number is and we can see how far we can move them apart by looking at the number from the serial print.

8.6 Full Prototype Testing

The full prototype had plenty of testing involved in the process of this design and its creation. Most of this testing however came from the previous design and their testing as the final prototype was just simply combining everything together. Since we already had all the parts working our full prototype didn't require specific part testing as we had already made sure the parts we included such as the emitter and its optics had already been tested. This however still caused problems as combining everything was difficult and required its own testing.

When combining the circuits most of the testing we had to do involved the hardware and software testing that we have talked about in previous sections. This involved using the multimeter to test voltages and using software to test if parts were inputting and outputting correctly. This however does not explain how we did it specifically in this design and how it helped us.

The first thing we did when we opened the Nerf gun up and connected it to the batteries was to see what the voltage was from the batteries using the digital multimeter. After reading just over 5V we knew it should be safe to connect to our Vin pin on the microcontroller so we connected it and ground to the ground pin and it worked turning our microcontroller on. Then we had to test to make sure the microcontroller was still functioning without being plugged into the computer so we wrote a simple software testing code to blink an LED connected to a GPIO pin. Once that worked without being connected to the battery we used the button on the dev board as an input to turn the LED on. Once we knew we could take inputs and outputs from the pre-programmed microcontroller while connected to a battery we knew we had the power source aspect of our demo down.

Next, we decided to test to make sure the inputs from our trigger and magazine buttons were readable and could be taken as inputs. This was a little more difficult because the buttons just produce a voltage when pressed down so we needed to read in an input voltage to our microcontroller. This voltage was 5V and we needed to connect a voltage divider circuit to bring it to the safe 3.3V for GPIO pins. After doing so we connected and tested both the trigger and magazine pins while the esp32 was connected to the computer so we could use serial write to see their values. Finally, we had the inputs from the button and the magazine fully working and we were ready to test the logic behind them.

When testing the logic we used a simple red LED as the output to make sure we could see it. After writing all the appropriate logic and programming the microcontroller we ran it and noticed it was not firing the right amount of bullets that we needed and the magazine was logic was broken. This was because the program was running too fast so if we clicked the trigger button it would run through multiple times and fire a bullet for each time and fire multiple times for each trigger press. Thankfully we noticed this issue by using serial print because since the trigger was being held down the LED would flash as normal so there would be no way of knowing from the outside. The issue with the mag was also similar as every time the loop would go through it wouldn't wait and would reload the mag instantly. This was an issue but the solution was fairly simple we needed to include loops after firing a bullet to wait until the trigger isn't pressed anymore to do anything else. For the magazine, we needed to loop once it was taken out and wait for it to be put back in to reload the ammo. This is just an example of some of the logic we implemented and tested in our design.

Once we had the battery, inputs, outputs, emitter, and optics testing done we just had to combine everything and test it to make sure it was working. Once the logic was working we had a fully built system and just needed to use the battery to power it and connect the optics system. After that, we built our prototype and the testing behind it was fairly simple and easy to do. To do this instead of using an infrared LED we used a red one so we could see the light that it produced to make sure it worked. We tested to make sure that the ammo and reload system were working and that all the inputs and outputs were working together accurately.

8.7 Evaluation and Plan

Evaluation and Plan is a huge step of testing and influences what the next steps of the project are. Evaluating the testing of your design can greatly improve the knowledge of its efficiency what parts are working well and what needs to improve. Once you know that planning comes into play you have to use what you learned in your evaluation to figure out what steps are next. Once you know what you need to fix you must find a good plan as to how to fix them and the best way to go about it. This is how all things are tested and improved upon in the world of product design, especially in prototyping.

8.7.1 Evaluation

Evaluation is a huge part of the testing process and influences the next steps of the design process. This is because once you evaluate your prototype you must be able to fully understand and show to others what is and is not working and what needs to be improved in the next prototype design. Evaluating your own project is very difficult sometimes as it can lead to personal bias of your own project so we are trying to keep this evaluation as neutral as possible to learn as much as we can from it.

Our evaluation of the project was actually fairly simple and didn't have that many moving parts but there's still much more we can learn from it to improve our next prototype. After evaluating the fully constructed prototype we have evaluated each section or part of the project itself and one of the entirety of the project. Doing this will help us distinguish which parts of the project need to be improved and which parts are working as we would expect.

The parts that did work well in our prototype and we are confident in them working for our final design are the ESP now wireless communication, inputs, haptic motor, and the ESP32 microcontroller. The ESP now communication has been working very well although we did not include it in the final prototype. Testing the communication has been great however have much more work to do on it to implement it into our next prototype. The inputs coming from sources like buttons have all been working great and we have had no problems with them in our design. The haptic motor has worked exactly how we planned it to and we only didn't include it in our final design because it worked too well vibrating and we didn't want parts to break. The ESP32 microcontroller has been working perfectly and we have had no issues with it in building our prototype.

The parts that worked but need improvement or to be tweaked for our next prototype are the optics, emitter, and receiver sensing distance. These all are combined basically into the same section and need to be tweaked a little to make sure that it works with efficiency. One of the main problems we have when using just an emitter and receiver is the range and although the optics will focus and help we still need much more testing in order to be confident to reach the goals that we set. With more testing and research we will be able to reach our distance and accuracy goals that we have set.

The parts that just aren't working too well and we need to improve is the LCD/OLED display. We have been having issues setting it up and making it function properly with our esp32. Another issue is that due to the size of the displays we have, we believe we will need a new size for our next and final prototype and want to start testing on the new ones as soon as possible.

8.7.2 Plan

Planning for the next steps of this project is crucial to making sure our final design has minimal to no design flaws and is done at the appropriate time. This can advantage us as having a good plan to build upon for our future prototypes and the final design will greatly increase its success as a project. This can also help us save time as having a good plan will help us work towards the right goals and not waste time doing the wrong thing and getting nothing accomplished.

The planning for this project and its upcoming prototypes is fairly simple as we need to evaluate each prototype's testing results and improve upon the parts that aren't working up to our standards. To do this we need to look at every section of the prototype to see what needs to be improved and make a plan as to how to improve them. Once we do this we can act upon it and hopefully fix the issues and improve upon every design until we get the desired final product.

The parts that worked well in our first prototype such as the ESP now wireless communication, inputs, haptic motor, and the ESP32 microcontroller don't need as much improvement but still need to be worked on. Since these parts are working well the main goal for them is to implement them into the newest prototype while making sure that they still work and function properly. Not only that but for the ESP32 and its ESP now wireless communication although they work they will still need major changes as we implement new systems into our design. Our plan for these parts is to not lose focus on them and make sure that they are always working and update them when needed.

The parts that worked but need to be improved upon such as the optics, emitter, and receiver sensing distance will not need any major changes but still require a lot of work. These parts not only require a large amount of work but also require loads of testing. This is because the optics design of this project is a very testing-focused part of the project and we need to make sure that it works how we want it. Our plan for these parts is to do more research and do loads of testing until we can get the results that we want in our project goals.

For the parts that didn't work as well as we thought such as the LCD/OLED display, we need to do loads more research on these products and then buy new displays that will work for what we require them to do. Our plan is that once we have the new displays we will get them working and hopefully be able to implement them into our next prototype properly.

9.0 Administrative Content

Administrative responsibilities shared between the members of the group are vital to researching and building a working project in the required time frame. There are many different administrative content shared between the members and each one contains as much importance as the next administrative content. Such administrative content contains budget estimates, team collaboration organization, and project milestones. Each one of these contains vital information or organizational tools to allow us to smoothly work on the project without missing a deadline or causing a huge obstacle. Without the organization of these topics, the project would most likely not be successful and would not be expected to finish before the final deadline during senior design II. Also, the team collaboration tools allow seamless communication between the members of the group and allow us to plan and enact group meetings that would allow us to establish very short-term goals within each week.

9.1 Team Collaboration Tools

Throughout the project, we used many different tools to properly organize team collaboration and establish group meetings. Tools such as lettucemeet.com and Discord allow us to have smooth communication during times when we are not face-to-face. Also, they assisted us in having a group meeting every week to establish the amount of progress we had made during the previous week. This is very important since we as a group believe that having consistent meetings every week will establish a smooth workflow and allow us not to fall behind or slack off during the days we do not have a meeting. Also in the case where a member does not understand the small part of the goal, these meetings would allow that member to discuss their confusion and solve the issue that they are experiencing. In the case of a few weeks before a deadline, we can as a group establish a hard deadline for the group before the actual deadline. In doing this strategy we allow some extra time before the actual deadline to proofread the paper or double-check the project to ensure that there would be no issue when submitting the progress we have so far.

Team collaboration tools such as Discord allow us to facilitate seamless communication and collaboration with the members of this project. This is especially true in situations where face-to-face interaction isn't possible or not needed. Its wide range of uses enables us to effectively exchange ideas, provide updates, and also coordinate tasks in real time. Some of the uses of Discord can be seen below.

1. Customized Channels: The ability to customize the different channels in Discord allows us to better dedicate specific chats to discuss specific topics, tasks, or milestones that we would need to achieve. This better organizes the different chats or talks and prevents possible clusters that would happen if there is only one chat.
2. Progress Updates: The ability to provide progress updates in the chats better assists this group in keeping track of the total progress to the next milestone. By scheduling check-ins, we can ensure that we are properly progressing the project to the next goal.

3. Document Sharing: The ability to send links and useful documents helps promote research and the ability to keep everyone up to date with the most relevant information. Also when answering questions or showing demos to the other members of the team we could simply utilize a video to explain the topic.
4. Regular Announcements: The ability to send announcements to the entire group helps keep the group on topic and also progress in finishing the project.
5. Virtual Meetings: Discord allows group meetings online through different voice chats on Discord. Through these voice chats, we are able to share our screen and also even show our webcam to encourage complete engagement by everyone on the team.
6. Data Storage: Within our group, we utilize Discord to properly manage different links with useful information or chats that contain relevant research to the project. One such example is having a chat that contains only the possible CAD designs of the laser gun CAD and keeping the chat only containing the designs. In this way, if we need to look back at previous prototypes or research we are able to easily find it in the chat.

In conclusion, these resources help us establish better communication and workflow within the group and assist us in establishing milestones and achieving those milestones. And also facilitates active participation within the group since it allows easy communication between the members. Instead of waiting for the next meeting, we are able to discuss issues or obstacles that we came across during the project and quickly discuss these issues. Without these tools, we would be unable to establish goals to achieve and properly plan out how to achieve those goals.

9.2 Budget Estimates

Establishing a budget is important for this project due to many varying factors such as budget allocation, communication of purchase, evaluation of cost-saving options, and many more. These factors will allow us to not only efficiently proceed with the project but also assist in making the most efficient product with the lowest cost. Especially factors such as communication between members and analyzing cost-saving opportunities are largely important. Communication between members allows to ensure proper compatibility between parts and also makes sure that no part is purchased more than needed and only a minimal amount is purchased every time. Also reviewing the overall budget list and comparing cost-saving opportunities would assist in ensuring that the project is researched and made in the most efficient way and also the cheapest way possible.

It is also important to create a budget list to analyze, review, and reflect on the effectiveness of the budget list at the end of the overall project. When making a final report or analyzing the overall project we can review the importance of the budget and see how much changed from the final budget to the budget we created at the very beginning of the project. And then analyze these changes to see what strategies we utilized were effective. And therefore gather effective strategies that we can utilize in future projects that we are a part of.

The specific merchant for these purchases has not been finalized, but some potential options are listed below in the parts hyperlink table. Additionally, the specific part or the quantity has not yet been confirmed, as we can make many different changes throughout the research and design process. Furthermore, many of the items are going to be sourced through pre-owned parts among each member so the estimated cost below might vary from the final cost at the end of the project.

Table 25. Budget Table

Part	**Part Description**	**Quantity**	**Unit Cost**	**Total Cost**
PCB Board	N/A	4	~$15	$60
MCU	N/A	4	~$15	$60
Rechargeable Battery	2000 mAh 11.1V	4	$19.99	$79.96
LCD Display	HD44780	2	$8.99	$17.98
LED lights	Multicolor 5mm	1 (Pack of 100)	$6.75	$6.75
Protective Vest	Black Tactical Vest	2	$28.99	$57.98
1kg Black PLA filament	2.85mm PLA Filament	2	$24.99	$49.98
IR LED	TSAL6100	2	$0.55	$1.10
IR Reciever	TSOP34856	10	$1.29	$12.90
Tactile Button	Tactile Push Button Switch	1 (Pack of 100)	$4.99	$4.99
Motors	ADA711	1 (Pack of 4)	$6.99	$6.99
Misc.	N/A	N/A	N/A	~$50
Combined Total				**~$408.63**

The budget for this project will be divided among the members of this project. As we progress and purchase each part, we will monitor the expenses and compile a final bill of materials report at the end of senior design 2 since this budget table just shows the first estimated budget.

9.3 Bill of Materials

A Bill of Materials or BOM is a very important document or chart that we need to keep track of during the progress and advancement of our project. This chart is meant to organize and keep track of all the purchases made toward the final project and to analyze what was used and was needed during the creation of the project. All the receipts and confirmation for the purchases made for the project will be kept track of in this chart and at the end of the project we can analyze and compare this chart to the original budget chart that we created at the beginning of the class.

Any product or purchased materials used during the project will be used in the Bill of Materials chart. This would not only include major components such as an MCU, power supply components, and overall physical body design but also any small components such as LEDs, buttons, kits, screws, and materials used to create the project.

Table 26. Bill Of Materials

Part	Part number or description	Quantity	Cost for each unit	Total Cost
Elegoo Uno R3 Project Super Starter kit	N/A	2	~$45	$90
1kg Black PLA filament[25]	2.85mm PLA Filament	1	~$25	$50
Infrared Emitters and Recievers[21]	5mm 940nm	1	~$5	$5
4pcs Breadboard Kit	2pcs 830 point 2pcs 400 point	1	~$9	$9
LED lights	Multicolor 5mm	1 (Pack of 100)	$6.75	$6.75
MSP-EXP430FR6989	MSP-EXP430FR6989	1	~$53	$53
ESP32-WROOM	ESP-WROOOM-32 CP2012 USBC	1 (Pack of 3)	$19.99	$19.99
Coreless Vibration Motors	7x25mm Vibrating Motors 1-6V 8000-200000 RPM	1 (Pack of 6)	$6.99	$6.99
Plastic Lens	Plastic Lens	6	~$0.45	~$2.70
Misc.	N/A	N/A	N/A	~$50
Combined Total				**~$293.43**

9.4 Milestones

For the project to flow and proceed smoothly, it is vital to maintain and keep good track of the different milestones and deadlines that need to be achieved during the creative process and design of this project. Without keeping a good track of flow and also keeping in mind the due date of the next deadline, we can easily fail to keep the deadline due to letting a large amount of work build up to the point where we would not be able to finish before the deadline. Many companies and groups struggle with this part due to not being able to have good administrative control and also failing to achieve certain deadlines at specific times. For this project, not achieving a deadline just simply deducts a letter grade at the end of the project. But for companies and professional groups, failing to achieve a deadline can have drastic and very major effects on the group or company. This can lead to not achieving and getting the budget supplied to them for the next product or even the company not achieving profit margins leading to a decrease in employment due to not having the money to support the company. In conclusion, it is very important to establish milestones or keep track of deadlines that we or any other groups need to accomplish to be successful.

Table 27. SD1 Milestones

SD1 Project Milestones				
Start Date	Estimated Date	Deadline Date	Task	Description
01/08/2024	01/11/2024	01/11/2024	Group Formation	Members: Ethan Hoang, Hussen Premier, Jasper Steensma, and Kevin Veciana
01/11/2024	01/26/2024	02/02/2024	Project Idea	Meeting outside or during class to discuss project ideas
01/11/2024	02/01/2024	02/02/2024	Divide and Conquer	10 page Divide and Conquer assignment
02/02/2024	02/06/2024	02/06/2024	D&C Meeting	Meeting with mentors to discuss D&C
02/06/2024	02/9/2024	02/16/2024	Update Website	Upload D&C to the website
02/06/2024	03/22/2024	03/29/2024	60 Page Report	Submit 60-page report milestone
02/06/2024	03/28/2024	04/04/2024	60-Page Report Me	60-page report meeting with mentors
04/04/2024	04/16/2024	04/23/2024	SD1 Report	Submit 120-page report

Table 28. SD2 Milestones

SD2 Project Milestones				
Start Date	Estimated Date	Deadline Date	Task	Description
08/21/2024	TBD	TBD	Gather Components	Gather all missing components for the final prototype
08/21/2024	TBD	TBD	PCB Schematic	Create and finalize the PCB Schematic and order the PCB for the prototype
08/21/2024	TBD	TBD	Overall Schematic	Finish the overall schematic for the project
08/21/2024	TBD	TBD	3D Parts Cad and Printed	Finish and print all 3D parts to assemble for the project
TBD	TBD	TBD	Prototype Test	Start the testing of the project
TBD	TBD	TBD	Prototype Adjustments	Troubleshoot any issues with the prototype
TBD	TBD	TBD	Prototype Completion	Finish the prototype to present
TBD	TBD	TBD	Project Finished	Finalize and fix small issues
TBD	TBD	TBD	Project Presented	Present the final project to the board

9.5 Work Distribution

Work distribution is an important aspect of managing large-scale projects involving multiple people. It involves assigning tasks to team members based on their skills, experience, and availability. When work is properly distributed tasks can be completed simultaneously causing a more efficient use of time. Each team members have a unique skill set and strength, without proper distribution, some team members might end up being overwhelmed and others left feeling useless or slacking off. Effective work distribution helps ensure a balanced workload. When tasks are clearly assigned, each team member has a specific area they are responsible for. This increases accountability, as each person knows exactly what they are responsible for. A fair distribution of work can also boost team morale. When everyone feels that they are contributing and their skills are being utilized.

Our team consists of four people, three of us are Computer Engineering majors (Ethan Hoang, Jasper Steensma, Hussen Premier) and one is an Electrical Engineering major(Kevin Veciana). The Computer Engineering majors in our team are primarily responsible for the software and embedded systems aspect of the project. They develop the software and implement the necessary game logic and the user interface to control key game settings. They also are responsible for programming the chips to handle wireless communication, player input, and haptic feedback. Hussen worked on the communication between the chips and setting up the web server that will be used. Furthermore, Jasper and Ethan focused on the IR emitter and receivers to create an initial. Jasper worked as well on the haptic feedback and getting a final prototype for our project. Hardware and PCB design is handled primarily by our Electrical Engineer Kevin. He created schematics and PCB designs for the laser tag guns and vests that accommodate all the necessary components like the ESP32 chip, power supply, sensors, IR LED, receivers, and more. Ethan has worked on designing, 3D model prototypes of our phasor gun and working on implementing the team vision when we will start 3D printing.

While working on the paper, everyone contributed about 30 pages give or take. We've built a system of constant in-person meetings and addition to keeping each other updated through messaging. We help each other out, double-checking each other's work and making sure everyone is on task. Jasper is our project manager primarily overseeing the team's progress, ensuring tasks are completed on time, ordering necessary parts, and facilitating communication among the team. Effective project management is crucial for the success of a large project like this.

10.0 Conclusion

Neon Knights started with a desire to create a fun project for senior design with the intention to replicate and improve a laser tag system. Many members of the group have fond memories of playing laser tag with home products that could be found in the public market. We also researched military uses of such products such as the MILES program in which they utilize a similar laser tag system with other mechanics to simulate a military simulation that could train soldiers to be better prepared. This report outlines the many different research and designs that we as a group have created during senior design I and will soon utilize in senior design II. Therefore as a result of the research and planning that is done in this paper, we gain more confidence in our ability to create and make the final prototype during senior design II.

Within our project and report, we analyzed the different components and aspects that other laser tag systems consist of, with this knowledge we implement systems that are not normally seen in other laser tag systems. One such aspect is the ability to reload using a proper magazine and be able to experience haptic feedback not only from the vest but also from the gun when you are firing using the trigger mechanism. The team is also looking to possibly implement multiple designs for the overall shape of the gun to allow users to customize and be able to experience different types of simulations and gameplays based on the gun or customization they have created.

One of the difficulties that can be seen when creating our project is the requirement of multiple PCBs since there are going to be four different units for users to utilize for our project. Each user is going to consist of a vest and a gun that are separate from each other and also our project for its starting point is going to consist of two users that can play and communicate with each other. Another aspect that we need to overcome is the different constraints that come with creating a system that looks similar to a real firearm. In public, this can possibly become a safety issue as hysteria in public can cause many different people to get hurt and injured. Overall these challenges are discussed and analyzed in our paper to overcome such challenges to make our project successful.

In the end, this project guided the members of the group in understanding the importance of researching and analyzing the different components that would be utilized in our project. Our demos and prototypes allow us to better understand each component before being placed into the first major prototype. Also in the process of creating the paper, we have a better understanding of the standards, safety, and constraints that come with creating a project as a group. Overall during this process, the members of the group better understand the importance of teamwork and organization to allow a smooth flow and ease of communication. Without these values, the project so far would have not progressed so smoothly and we as a group would have probably not been able to achieve any of the deadlines placed on us during the semester. As a group, we hope to achieve more than what we plan and be able to stretch further than the simple goals that we have placed during the beginning of the semester. We hope to be able to gain skills and knowledge that will assist us later in the future and be able to utilize the experience gained from this project to make ourselves better engineers and further graduate with a project that we as a group are satisfied with.

Declaration:

We hereby declare that we have not copied more than 7 pages from the Large Language Model (LLM). We have utilized LLM for drafting, outlining, and comparing.

Appendices

Appendix A: References

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Appendix B: Copyright Permissions

Request information about the IR protocol and how to implement data into infrared

HP Hussen Premier

Reply Reply all Forward

To: info@laserwar.com

Hello,

My name is Hussen Premier, and I am a senior student at the University of Central Florida. I am currently working on my senior design project, which involves wireless communication. As part of this project, I would like to use the information in the for the OpenLaserTag IR protocol: https://openlasertag.org/language/en/openlasertag-ir-communication-protocol/. I believe that your material will greatly enhance the quality of my project and provide valuable insights.

OpenLaserTag IR protocol – OpenLaserTag

ShareOverview OpenLaserTag protocol is based on the MilesTag II protocol, extends its capabilities and is backward-compatible with this protocol. Allows up to 32767 unique player ID, 15 bits for player ID. It allows Big Game for many players. The last 1024 IDs reserved and indicate anti-materiel weapons. This fully penetrate armored target. Modulation The protocol uses [...]

openlasertag.org

Thank you for considering my request. I look forward to hearing from you soon.

Best regards,
Hussen

Reply Forward

Request usage of information about I2C

HP Hussen Premier

To: support@sparkfun.com

Hello,

My name is Hussen Premier, and I am a senior student at the University of Central Florida. I am currently working on my senior design project, which involves wireless communication. As part of this project, I would like to use the information provided in the I2C tutorial: https://learn.sparkfun.com/tutorials/i2c/all. I believe that your material will greatly enhance the quality of my project and provide valuable insights.

Thank you for considering my request. I look forward to hearing from you soon.

Best regards,
Hussen

Request information about infrared communications

HP Hussen Premier

Reply Reply all Forward

To: info@lasersafety.com

Subject: Request for Copyright Permission for Senior Design Project

Hello,

My name is Hussen Premier, and I am a senior student at the University of Central Florida. I am currently working on my senior design project, which involves IR communication.
As part of this project, I would like to use the 'Depth of penetration of electromagnetic radiation in the human eye' figure from the laser safety guide (https://lasersafety.com/resources/laser-safety-guide/). I believe that your material will greatly enhance the quality of my project and provide valuable insights.

Thank you for considering my request. I look forward to hearing from you soon.

Best regards,
Hussen

Reply Forward