Neon Knights

Kevin Veciana, Jasper Steensma, Hussen Premier, Ethan Hoang

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — The Neon Knights project showcases a sophisticated demonstration of a hardware-software interface designed to create an advanced laser tag system utilizing infrared technology. The system comprises a phasor and vest, each with a dedicated PCB and an ESP32 microcontroller to perform system operations and communicate wirelessly via Wi-Fi. Key innovations include an IR receiver and emitter for seamless and accurate hit detection, haptic feedback for a truly immersive experience, and an LCD for instant feedback on actions performed. The design incorporates common engineering principles with an emphasis on reliability, user experience, and scalability. This project aims to enhance the traditional laser tag experience by making the system more accessible while delivering superior performance.**

***Index Terms* — Laser tag technology, infrared communication systems, wireless communication, sensor technology.**

I. Introduction

Using modern hardware and software technology, the Neon Knights project redefines the traditional laser tag experience. The phasor is designed to resemble a more realistic laser tag gun, featuring an IR emitter for precise targeting, customizable fire rates, a reload system, RGB LEDs, and haptic feedback motors—all created to provide an immersive experience for the user. An LCD display is attached to the phasor, facing the user, to provide live game statistics such as scores, hit percentage, and remaining health.

The vest, on the other hand, includes multiple IR sensors distributed across different zones to maximize hit detection accuracy. When a hit occurs, LEDs and haptic vibrations are activated to notify players of the specific zone in which they were hit. Wireless Wi-Fi communication allows seamless data transfer from the phasor to the vest, enabling specific game interactions to be displayed on the LCD of the phasor.

System specifications include a vest and trigger response time of less than 1 second, ensuring swift activation of the IR laser upon pressing the trigger and rapid sensor detection of the IR light. The IR receiver accuracy is approximately 80%, and the system's battery provides at least 2 hours of playtime. The vest includes four distinct detection zones, with a minimum system voltage of 5 volts. The infrared light wavelength used is 940 nm, and the motors can spin up to 16,000 RPM at 3 volts.

II. System Hardware

A majority of our research focused on the hardware components of our system, as its functionality relies heavily on these components. Background for each of the technical components will be provided in this section.

A. Microcontroller

This project opted to use the ESP32-WROOM-32D, which features an integrated low-power Wi-Fi module. Through this MCU, we control all components in the phasor and vest, and we use the Wi-Fi module for wireless communication.

Specifically, the MCU in the gun manages trigger control by processing the trigger input and activating the IR emitter, simulating a shot fired in the laser tag game. It also monitors fire rate and reload management, allowing for customizable fire rates (e.g., single-shot, burst, automatic) and resetting the ammunition count when the reload button is activated. The LCD that is implemented in the phasor that faces towards the user during gameplay is updated with real-time game statistics through the wireless communication provided by the MCU. The haptic feedback control and RGB LED management is all controlled through MCU and set to go off when the trigger is activated.

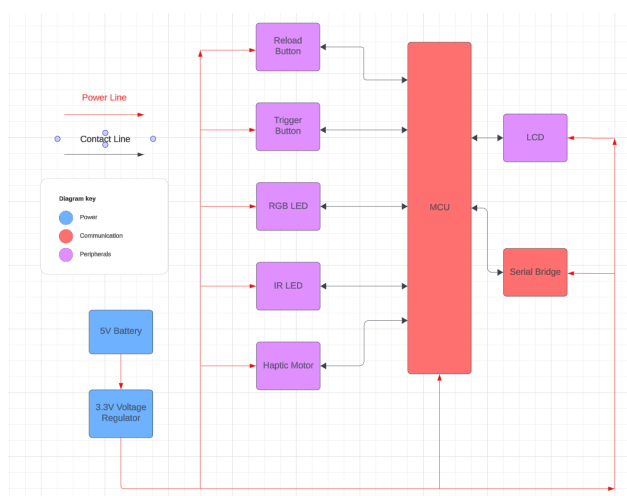

Fig. 1. phasor hardware flowchart.

For the vest, excluding the LCD, trigger and reload buttons, the same components are used and managed by the MCU in the same way. The IR emitter is also replaced by the IR receiver and using the MCU the system can detect signals received from the IR sensors and can detect a hit and which zone was hit. The MCU when it detects a hit has been made activates the haptic feedback motors and LEDs on the vest to notify the player of the hit and which specific zone in which the hit occurred. The MCU on the vest also takes care of the data logging and transmission wirelessly through WiFi to the phasor.

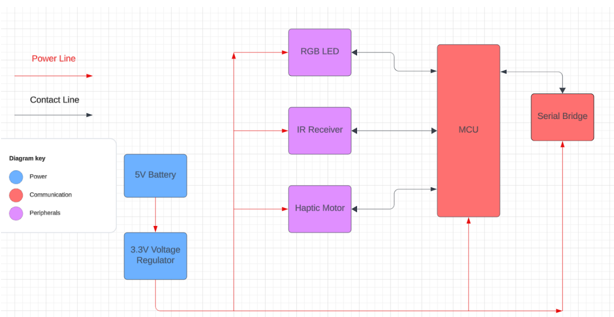

Fig. 2. Vest hardware flowchart.

B. High Power Infrared Emitting Diode TSAL6200

The IR emitter for this project is the TSAL6200 which is a high-power infrared emitting diode which is often used for applications where a focused IR light emission is needed (i.e. remote controls, optical communications, etc); for the case of the Neon Knights project, it is needed for a laser tag system. [1] The TSAL6200 emits light at 940 nm, invisible to the human eye, which best for a laser tag experience. [1] The high radiant intensity (40 mW/sr at 100 mA) is also essential for laser tag as it allows for the system to emit a strong and focused beam. This also goes along with the narrow emission angle (±10° half-angle) which is ideal for laser tag applications. [1] The high-speed switching (general <15 ns) is particularly important as well since this means pulses of the IR laser can be achieved very quickly and provide the player with a better feeling laser tag experience. [1] The high forward current tolerance (100 mA) is responsible for the ability to emit a more powerful signal without risk of overheating. [1]

C. IR Receiver Module TSOP4838

The TSOP4838 is a high-performance IR receiver module designed to detect infrared signals modulated at 38 kHz.[2] This frequency is ideal for our project, as it significantly reduces interference from other infrared sources, such as sunlight or indoor lighting, which are typically not modulated at this frequency.[2] By using 38 kHz modulation, the TSOP4838 can accurately detect signals from our IR emitter while filtering out unwanted background noise. [2]

The TSOP4838 is also highly sensitive, providing reliable signal reception up to approximately 45 meters. [2] This sensitivity is advantageous for laser tag applications, allowing for free movement and precise gameplay within the 45-meter range.[2] Additionally, the module's automatic gain control (AGC) helps filter out ambient IR noise by adjusting the receiver's sensitivity based on the strength of the incoming signal. [2]

Finally, its wide supply voltage range (2.5V to 5.5V), fast reaction time (10-50 μs), compact design (7.5 x 5.3 x 4 mm), and low current consumption (0.4–1.5 mA) make it an extremely beneficial choice for our project.[2]

D. AMS1117 3.3V Low Dropout Voltage Regulator

In the laser tag phasor and vest, the AMS1117 3.3V low dropout voltage regulator is used to provide a stable 3.3V power supply to the MCU, ensuring reliable performance. The choice of a low dropout voltage regulator (LDO) was crucial because the system is battery-powered, meaning the input voltage is close to the desired 3.3V output. This made the LDO design necessary to maintain stable voltage regulation with minimal energy loss.[3]

The AMS1117 3.3V regulator can supply up to 1A of current, which is more than sufficient to power the MCU and sensors within the laser tag system. This ample current capacity supports multiple components without the risk of overloading or voltage drops, ensuring smooth operation during gameplay.[3]

Additionally, the AMS1117 includes built-in thermal protection, which automatically shuts down the regulator if overheating occurs. This is particularly useful if improper connections are made or during extended usage, protecting the regulator and other components from damage. Furthermore, the regulator features short-circuit protection, which limits current flow in the event of a short circuit. This provides added protection for both the regulator and connected components, reducing the risk of system failures during intense gameplay.[3]

Finally, the compact SOT-223 package of the AMS1117 makes it an ideal choice for the system's PCB layout, where portability and space efficiency are key design goals. The small size of the regulator allows for efficient board design without compromising functionality.[3]

E. Power Supply Unit

The power supply for our system uses AA batteries for both the phasor and the vest, with each powered by 4 AA batteries. This option offers several advantages over other power sources. One obvious reason for this choice is the widespread availability of AA batteries; most people already have them at home, which was a major influence on our decision. Another reason is cost-effectiveness, as AA batteries are far cheaper than any other option. With each battery providing 1.5V, it was straightforward to connect 4 in series to meet the power requirements needed to run the system.

The high energy density of AA batteries also ensures that the system has a sufficient power supply for an extended period while keeping the design as compact as possible. In case of power depletion or issues with the power supply, AA batteries allow for quick and easy replacement, which is advantageous in a game setting as it enables rapid gameplay resumption.

Additionally, the availability of both disposable (alkaline) and rechargeable (NiMH or lithium) AA batteries offers flexibility, making it possible to implement a rechargeable system if desired. Finally, AA batteries provide a safe and stable power source, offering peace of mind with minimal risk of overheating or, in extreme cases, explosion.

F. Haptic Feedback

The Eccentric Rotating Mass (ERM) motor is a type of electric motor with an off-center weight attached to the shaft. When the shaft rotates, the unbalanced weight creates a "rumble" or vibration sensation. ERMs are valued for their simplicity, low cost, and robustness due to minimal moving parts, making them durable and resistant to wear. They are particularly effective for applications requiring strong vibrations, as ERMs produce significant vibrational force.

H. 1.44 SPI Module MSP1443 LCD

The MSP1443 is ideal for our laser tag project due to its compact size and high-end features. This small and lightweight 1.44” display is a perfect choice for the phasor, allowing us to provide the user with information about health, ammo, score, and more, without adding bulk. With a 128 x 128 pixel resolution, the LCD offers clear and legible data. The LCD integrates seamlessly into the stock of the phasor, fitting unobtrusively.

The MSP1443 uses SPI for communication, enabling the fast and efficient data transfer required for a laser tag system. Additionally, it supports up to 65K colors, allowing us to create dynamic visuals to indicate certain statuses (e.g., different team colors, red for low health, green for good health), making the game more visually engaging for the user.

The display’s low power consumption and backlight support longer game sessions and ensure readability in both dark and bright environments. Its durability and ease of integration streamlined the build process, making it an excellent choice for the Neon Knights project.

III. System Software

In our laser gun design project, a background software program will manage the game’s status and relay information about the game and each player’s current situation. A microcontroller will facilitate communication between the various hardware components and send the gathered information to the software program.

The software flow begins with loading initial game information onto the player’s gun screen. It then activates all necessary components, such as sensors, emitters, and motors. After initialization, the game selection screen will appear on the LCD, allowing players to choose the game mode. At this point, the software will split into two separate threads: one for the laser gun and one for the vest that players wear.

The laser gun software will start by waiting for the trigger to be pressed. When the trigger is activated, the program will check if the gun’s magazine has ammunition. If so, the gun will "fire" by activating the infrared emitter. If a player is hit by the IR beam, the sensors on their vest will detect it, and the software will calculate the player’s remaining health. If the player’s health reaches zero, the game will end, and the player will have the option to restart and play again.

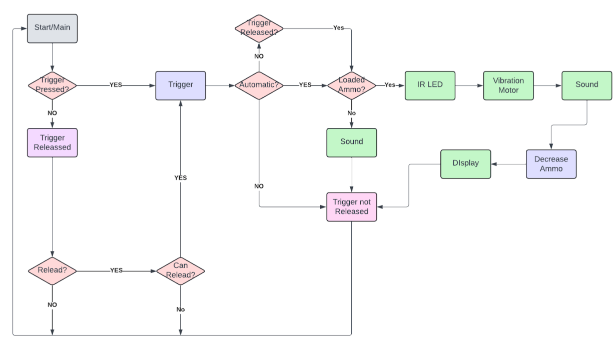

Fig. 3. Phasor software flowchart.

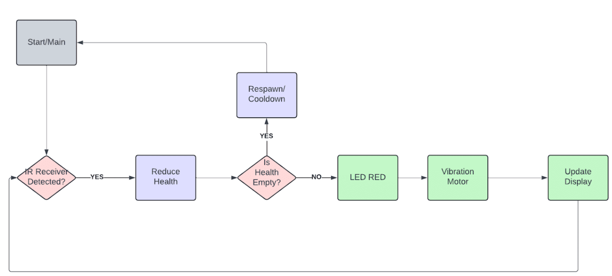

Fig. 4. Vest software flowchart.

A. Wireless communication protocol

For wireless communication, this project found Wi-Fi to offer the most benefits. Unlike Bluetooth, Wi-Fi provides a significantly longer communication range, typically operating effectively within or up to 50 meters—ideal for this project, as IR detection reaches up to 45 meters. Long-range movement is not a limitation for the Neon Knights laser tag project, largely due to Wi-Fi's extended range.

Wi-Fi's high data transfer rates also enable seamless transmission and reception of data, ensuring real-time updates for the user. Additionally, Wi-Fi can support multiple devices simultaneously, making it possible to expand the player pool easily by adding extra gear. Compared to Bluetooth, Wi-Fi is less susceptible to interference, providing a more reliable and stable connection.

Like SPI, Wi-Fi supports full-duplex communication and offers low latency. Another advantage of the Wi-Fi module is its power-saving "sleep mode," which helps reduce battery consumption. Ultimately, Wi-Fi was chosen for its wide availability, ease of integration into embedded systems, and abundant resources, including libraries, setup guides, and troubleshooting support.

B. Communication Protocol

SPI offers numerous benefits that make it ideal for the laser tag system. One major advantage is its faster data transfer speed compared to other protocols available on the ESP32 MCU, such as I2C or UART. SPI can operate in a wide range of frequencies (in the MHz range), enabling real-time data transfer, which is essential for a smooth laser tag experience. This capability is crucial for features such as immediate hit detection, score updates, and LED and haptic feedback mechanics, all of which contribute to a seamless gameplay experience.[4]

Another advantage of using SPI is its full-duplex communication, allowing it to send and receive data simultaneously. This feature is beneficial for the Neon Knights project, where the phasor can send firing signals while the vest sends hit detection feedback back to be displayed on the LCD. This enables near-instant updates of scores or hit results, enhancing the immersive experience for the user.[4]

Additionally, SPI is a simpler protocol than I2C, as it does not require start and stop bits, resulting in lower latency. SPI also allows for dedicated connections for each device through individual SS/CS lines. This setup enables multiple devices to communicate with the master without complex addressing, making it easier to add additional components, such as another LCD, with minimal risk of interference.[4]

SPI is also known for consuming less power because communication completes quickly and does not require repeated start/stop conditions, as I2C does. This lower power consumption is crucial for extending the playtime of the system, especially given the limited power source.

Another beneficial feature of SPI is its flexible clock polarity and phase, which is advantageous in projects that use a variety of sensors, displays, and feedback modules, as in this laser tag system. This flexibility allows for smooth configuration of communication timing, ensuring that all components work synchronously.[4]

Finally, SPI enables a simpler circuit design, requiring only four wires, which is valuable for any senior design project where compactness and simplicity are priorities.

IV. Phasor Housing

A. 3D Printer

The Ultimaker 3 offers highly precise printing and supports dual extrusion, allowing for the use of either two colors or two different materials simultaneously. It is the ideal printer for this project because it enables the detailed, accurate printing needed to showcase all the features of the gun design. With its capability to print large overhangs, the need for support structures in the design is reduced, resulting in a smoother and more refined appearance for the gun. Additionally, having personal access to an Ultimaker 3 ensures a seamless workflow and efficient production and testing for the design. This allows us to achieve the desired aesthetics and functionality for our laser gun model. Overall, the Ultimaker 3 is an excellent choice for a 3D printer due to its accessibility, versatility, and reliability, enabling us to create the 3D housing for our laser tag system.

B. 3D Modeling Software

Our group decided to use Onshape because it is free for students and allows for easy sharing and exporting between group members. Additionally, there is no need to download the software onto a PC, as it can be accessed directly through a browser. This enables group members to work on the CAD design from any location and on any computer with internet access.

C. 3D Printing Materials

Polylactic Acid, or PLA, is derived from renewable resources such as cornstarch or sugarcane, making it environmentally friendly and biodegradable. It also has a low melting point, which improves the quality of the

printing process by reducing the risk of warping during printing. This helps the printer achieve smoother, more precise prints with a lower likelihood of failure during the printing process. Additionally, PLA emits fewer unpleasant and toxic odors compared to materials like ABS.
However, PLA has some drawbacks. It has lower heat resistance and can soften or melt on a very hot day, limiting its use in high-temperature environments. Also, because it is biodegradable and environmentally friendly, PLA is not ideal for prolonged outdoor use without protection, as exposure to the elements will accelerate its biodegradation over time.

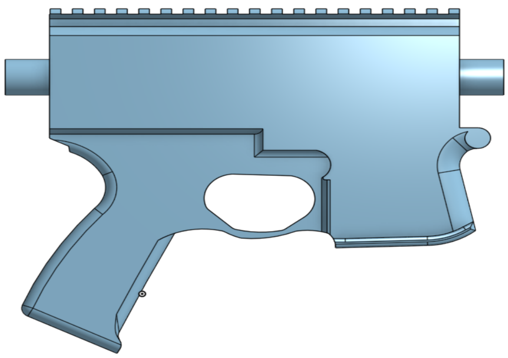

Fig. 5. Main housing CAD prototype.

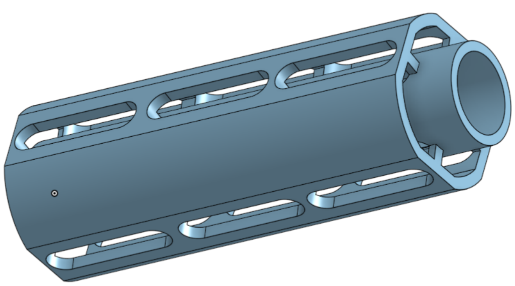

Fig. 6. Lens/Barrel attachment CAD prototype.

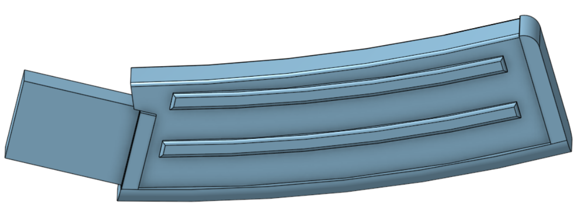

Fig. 7. Magazine attachment CAD prototype.

VI. Board Design

A. PCB Design Software

The design software that was chosen to develop the PCB for the Neon Knights project was EasyEDA. EasyEDA has several advantages over other PCB design software because it is web-based, accessible from anywhere, and does not require a download. With EasyEDA's incredible accessibility, users can work on their design projects from any location with an internet connection, without limitations on which devices they use. This flexibility allows users to decide when, where, and how they want to work. For teams facing location barriers, EasyEDA is an excellent option, as it enables real-time collaboration without any installation or configuration process. One of the most attractive features of EasyEDA is its ability to allow multiple users to view and edit a document simultaneously, similar to Google Docs or other collaborative software. This collaborative capability increases efficiency in the design process, especially for tasks such as reviewing and editing, often saving significant time. EasyEDA also automatically saves changes and stores these versions, allowing the team to revert to previous versions if any mistakes are made or changes need to be undone.

Another major advantage of EasyEDA is its direct integration with one of the largest PCB manufacturers, JLCPCB. This integration allows users to order their PCBs directly through the platform as soon as they finish designing. EasyEDA also verifies that the design is compatible with JLCPCB's manufacturing capabilities before ordering, helping to reduce errors and mistakes in the ordering process.

However, EasyEDA does have limitations that may make it challenging or even impractical for some users. Unlike other platforms, EasyEDA relies on a stable internet connection. In many parts of the world, a reliable internet connection may be difficult to obtain, and when traveling, it can be challenging to access a steady connection. If the internet connection is lost before the software has automatically saved the project, there may be a loss of work, and without a connection, no projects can be accessed. Additionally, being web-based can lead to occasional performance issues, especially with larger or more complex PCB designs, where desktop platforms typically perform better. Even if EasyEDA is downloaded, many features are restricted without an internet connection. Other desktop applications, by contrast, offer fully functional offline versions, providing more capabilities for projects without requiring an internet connection.

B. PCB Design Philosophy

The PCB is designed to be compact and cost-effective while maintaining full functionality and durability. Ease of manufacturing is also a critical aspect of the project, so we ensure the PCB is designed in a way that is simple and cost-effective for manufacturers to produce. Another key design principle we follow is testability, ensuring that we can easily test and troubleshoot the PCB. This process includes adding test points, acquiring the appropriate testing equipment, and arranging component placement to facilitate testing.

Minimizing noise is essential to prevent circuit degradation. By following best practices in trace routing, shielding, grounding, and using decoupling capacitors, we can reduce the effects of noise and interference. Proper thermal management is also essential to ensure the PCB performs consistently across all expected performance ranges. Techniques such as heat sinks, thermal vias, and strategic component placement contribute to full reliability.

Ensuring compliance with PCB standards supports our efforts to achieve compatibility with different components and to meet quality and safety regulations. Lastly, optimizing the design for efficient assembly and using simulation tools helps minimize wasted time, errors, and costs.

C. PCB Design

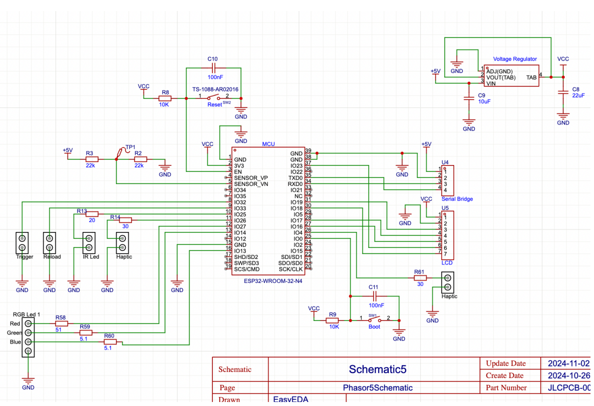

Fig. 8. Phasor schematic.

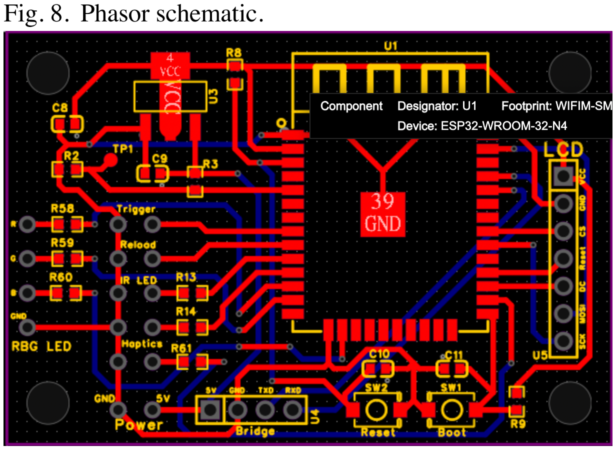

Fig. 9. Phasor PCB.

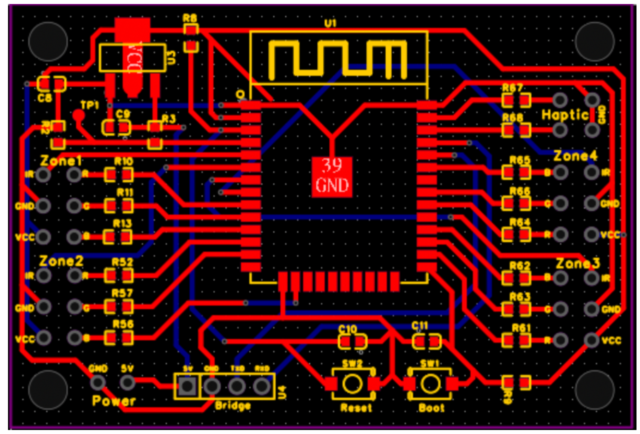

Fig. 10. Vest Schematic.

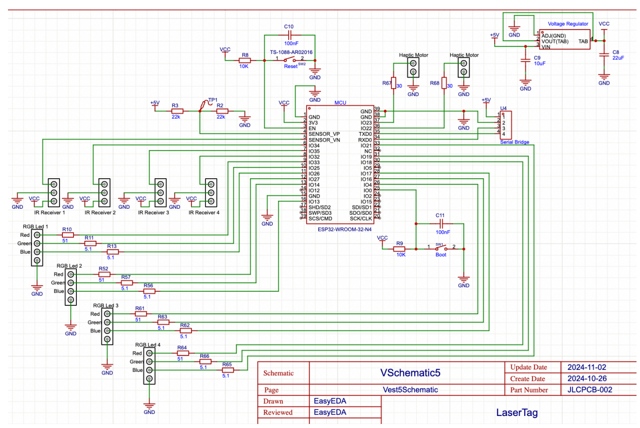

Fig. 11. Vest PCB.

The PCB is the main connector of components in this project. Our primary goal on the hardware side is to design an advanced PCB that is compact, effective, and durable. To achieve this, the PCB will connect the MCU, controllers, and Wi-Fi module, ensuring efficient communication among these components. A PCB is essential to create an optimal, industry-standard design. We plan to make our PCB single-sided with one copper layer, given our low component density.

The main PCB's development and design will be done using Autodesk Eagle software, an industry-standard tool. Before beginning the design, we'll select available parts for order. Eagle offers features that greatly aid PCB design, including a layout editor supporting complex, multi-layer designs, a schematic editor for easy circuit drawings, and an extensive library of component footprints. Once the design is validated and manufacturing files are generated, we'll select a PCB manufacturer, such as RushPCB, to bring our design to life.

The PCB's main purpose is to connect internal components like resistors, capacitors, and integrated circuits by physically attaching them to a substrate in an organized manner, simplifying their interconnections. Additionally, the PCB distributes power from the source to the various components, ensuring proper voltage and current levels for correct operation.

The advantages of a PCB are vital to our final design. A PCB connects different components through a carefully designed layout using etched copper tracks. For complex circuits requiring substantial wiring, a PCB is the most feasible solution due to its compact, reliable design that simplifies component connections. Additionally, a PCB minimizes interference, noise, and signal loss through precise trace layout calculations, which is crucial for high-speed and high-frequency electronics. When high-power components are involved, the PCB manages heat effectively through copper traces, thermal vias, and heatsinks. In today's technology, automated PCB production allows for cost-effective, mass-manufactured electronic devices. Overall, PCBs offer significant benefits: efficient electronic connections, signal integrity, power distribution, heat dissipation, compact design, reliability, and cost-effective manufacturing. Without a functioning PCB, the entire project would be inoperable, making it the single most critical component.

To connect various components to the PCB, we must consider additional circuits to ensure proper functionality. For example, the MCU requires a voltage regulator for stable voltage levels to itself and other components. A Power Management IC (PMIC) is beneficial for managing the system's power requirements. Filtering capacitors will also be used to decouple ICs or regulate power fluctuations. Additionally, a display interface such as an LCD display will be incorporated.

Several PCB qualities enable the integration of all our components, including the MCU, RGB controller, and Wi-Fi/Bluetooth module. Conductive traces and pads are essential, with traces acting as electrical wires on the board to connect different components. Pads are small copper areas where component leads or pins are soldered, providing physical contact points between the PCB and components. Layering allows multiple conductive traces separated by insulating material, enabling different layers to carry distinct signals and power levels, resulting in a more compact, complex design.

Vias, including through-hole, blind, and buried vias, are critical for interlayer connections. Through-hole vias connect multiple PCB layers, while blind and buried vias provide similar functionality without fully piercing both sides of the PCB. To establish a secure electrical connection, each component must have a designated solder point. Silk-screening is strongly recommended for identifying component locations and orientations, printing labels, and adding any other helpful information, making assembly and troubleshooting easier.

The PCB's surface finish, applied to copper traces and pads, prevents oxidation and enhances solderability, improving durability. Finally, including multiple test points for electrical testing is highly recommended to ensure all connections are functioning properly and there are no short or open circuits.

VII. Embedded System Design

Embedded system design is a crucial part of the project's software development and will significantly impact its overall functionality. This design enables us to control the entire project from the microcontroller within the embedded system, allowing us to manage, update, and read inputs from the environment. Having such control over the project is essential for ensuring smooth operation and overall project success.

Our project's embedded system is essentially a set of logic rules that convert specific inputs into distinct outputs. This logic enables the embedded system to take inputs from various sources, such as the infrared receiver, trigger, magazine, and master terminal. These inputs are registered within the microcontroller's internal system and processed to produce outputs for components like the infrared emitter, LEDs, LCD, and haptic feedback motors. All inputs and outputs are connected to the microcontroller either through direct wiring or, in our final design, through the printed circuit board (PCB).

There are multiple approaches to embedded system development, each with its own methods to achieve functionality. We are using the ESP32 microcontroller, which supports the Arduino IDE and C/C++ programming languages. Using C++ for embedded software development offers features beneficial to our design, such as object-oriented programming (OOP). OOP principles provide useful tools like polymorphism, classes, objects, and inheritance, which are invaluable in organizing and structuring software.

While embedded system design is essential, the quality of the software design is equally crucial for project organization and functionality. A well-structured and thoughtfully organized embedded system code makes the project easier to understand, update, and debug. To achieve this, we'll take a step-by-step approach, dividing the code into subsections to enhance structural integrity. Object-oriented programming will be an invaluable tool in this organizational effort.

OOP will play a major role in organizing our software, making it easier to add new features, debug, and increase readability. We plan to divide the code into smaller sections and use objects to improve organization. This approach allows us to create objects for aspects like game modes, teams, players, phasor, vest, and more. For example, a game mode will contain teams, which contain players, each with a phasor and vest. This object hierarchy makes it simple to create new classes or objects, facilitating feature additions in our embedded design.

Our main software flow will involve a central runner that first prompts the user to select a game mode, creating a game object based on the chosen mode. The game mode class will contain various elements, depending on the mode selected, but all modes will share certain requirements, such as needing team information before starting the game. Once team information is provided, team objects will be created, each containing team stats and player objects. Each player object will hold player information and stats, as well as vest and gun objects that the player will use. The vest and phasor objects will contain even more information and act as the main inputs and outputs for the design.

The code within most objects will be relatively simple, containing only information relevant to that object. However, the phasor and vest objects will differ, as they need to connect to inputs and outputs. We'll implement code that can read from and write to inputs and outputs, with additional logic to determine appropriate outputs based on the received inputs.

The Engineers

Hussen Premier is a 21-year-old graduating Computer Engineering major with a minor in Intelligent Robotic Systems. His career goal is to work at the forefront of technological innovation, applying his skills to design and develop cutting-edge solutions that push the boundaries of engineering and robotics.

Jasper Steensma is a 21-year-old Computer engineering student. Jasper plans to further his education and pursue a master's degree. Jaspers career goals are to work in software development or embedded systems engineering.

Ethan Hoang is a 22-year-old Computer Engineering student with aspirations to pursue a career specializing in computer hardware. His career goal is to work for a large computer hardware company like Intel or AMD. He is particularly interested in research and development.

Kevin Veciana is a 22-year-old Electrical Engineering Student. Kevin is currently pursuing a job in construction engineering and design with local companies in Orlando, such as Burns & McDonnell, HDR, and Exp, and has received an offer from Bechtel NS&E.

Acknowledgement

The authors wish to acknowledge the assistance and support of Dr. Xin Xin, Michael McAlpin, Dr. Gonzalo Vaca, Dr. Chung Yong Chan, Dr. Lei Wei, and Dr. Arthur Weeks; University of Central Florida.

References

[1] TSAL6200: High Power Infrared Emitting Diode, 940 nm, GaAlAs," *Vishay Intertechnology, Inc*. Datasheet, 81010, pp. 1-9, 2003. Available: https://www.vishay.com/docs/81010/tsal6200.pdf

[2] Vishay, "TSOP48.. Series IR Receiver Modules for Remote Control Systems," Vishay Intertechnology, Inc., Datasheet, 2003. Available: https://www.vishay.com/docs/82459/tsop48.pdf

[3] Advanced Monolithic Systems, "AMS1117 3.3V Low Dropout Voltage Regulator," Advanced Monolithic Systems, Inc., Datasheet. Available: http://www.advanced-monolithic.com/pdf/ds1117.pdf

[4] Valvano, J. W., "*Embedded Systems: Real-Time Interfacing to ARM Cortex-M Microcontrollers*", 4th ed. Jonathan https://www.valvanoware.com

[5] LCDWIKI, "1.44inch SPI Module MSP1443 User Manual," LCDWIKI, Datasheet. Available: http://www.lcdwiki.com/res/MSP1443/1.44inch_SPI_Module_MSP1443_User_Manual_EN.pdf