Laser Target-Shooting

Divide and Conquer
EEL 4914 Senior Design I
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Group 6

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Background

Recreational shooting is a pastime that gun owners do to sharpen their shooting skills or do simply for fun. However, most people do not have the luxury of being able to shoot a firearm near their home and must go to a local shooting range for practice. At shooting ranges, for people who do not bring their own equipment and must rent, prices can easily get up to a hundred dollars per hour. Unequipped visitors not only have to rent expensive ear and eye protection, shooting lanes, and guns but must also purchase the ammunition being used in their firearm of choice. Renting a fully-automatic firearm from some firing ranges can be as high as three times the price of renting a standard semi-automatic pistol. For visiting gun owners, they have to drive to their local range, bring their equipment, and rent a shooting lane. Overall, this process can be very inconvenient.

There are alternatives to firing ranges such as using Airsoft guns or living in areas where firearms can be fired in backyards, but these solutions involve firing lead and plastic rounds outside which can have negative effects on the environment or can cause accidental injuries or property damage if no precautions are taken. Regarding Airsoft in particular, firing these weapons are much safer than firing real firearms; however, the lack of recoil and the lack of power in the BB pellets fired makes for an unrealistic and unsatisfying shooting experience.

Project Motivation and Goals

Going to a fire range is not something that everyone is able to spend their time or money on. Our project aims to bring the firing range experience to your home by creating a laser rifle and an electronic target board. At its foundation, our project involves using a rifle that fires a laser beam out of the barrel to strike a target board that lights up an area where the beam strikes the surface of the board. By using lasers, the downsides of using live ammunition such as danger, environmental impact, deafening gunshots, and high cost are improved upon, while portability and accessibility is increased as lasers are not treated the same as live firearms. Overall, a cheaper, safer, and more portable shooting experience is created. While this idea is not new in the market, our project also aims to improve on other products in terms of realism, safety, and convenience. With similar products prices going from $100 to over $500 for laser training systems, features vary heavily.

The cheapest systems include ones such as the Strikeman Training System and LaserHIT that involve using $40+ battery-powered “laser cartridges” that are placed into real firearms and fire visible light lasers when the trigger is pulled. As shown in Figure 1, these systems use custom software, such as an app using a phone camera, that tracks the location of where a shot is made on a projector screen or physical target. These systems are typically around $100 or more. Since real firearms are being used, these systems are realistic in the handling and aiming aspect, but since no actual rounds are being fired, there are no shooting elements like recoil or even gunshot sounds. Pulling the trigger is no different from pressing a button on a TV remote. Every shot fired requires the round to be rechambered using the slide on a pistol or the pump on a shotgun, so no full auto is possible using these systems.

Figure 1. Strikeman Training System

Larger scale systems such as Laser Shot and Laser Ammo actually provide training to military and police personnel. While offering their own simulation systems, prices are extraordinary at over $500 for the cheapest laser weapons they have to offer. Their laser weapons come with recoil simulating CO_2 canisters similar to those used in Airsoft guns and have the option to either be visible or IR light. Gunshot sounds play when weapons are fired. Shown in Figure 2, these systems are typically used with simulation software that connects to large projectors where users can play various types of aiming training games. They have many features that try to simulate real firearms at the cost of low portability.

Figure 2. Laser Shot

Finally, systems like LaserLyte provide a different approach to the laser cartridge systems at around $150 for a pistol and $200 for a physical target board. These systems typically use pistols with visible laser diodes installed into them. The pistols are typically aimed at physical, electronic targets that play sounds and light up LEDs when fired at. Overall, these share the same flaws as laser cartridge systems and are limited to gun-shaped laser pointers. Compared to the more expensive systems, these are the most portable systems, but as shown in Figure 3, the targets used are typically very small. More expensive target boards have precise tracking that counts score depending on where a shot was made like in darts. These systems are the least realistic in all aspects but are highly portable.

Figure 3. LaserLyte

Taking into account all of these flaws and features that each system brings, we aim to make a laser target-shooting system that is an overall improvement on market products. As most people go to firing ranges for entertainment and training for firearm handling or military purposes, our project also keeps these core goals in mind when deciding project features. Our project aims to make a laser rifle and target board that will have a plethora of features that prioritize realism, safety, and user convenience.

Laser Rifle

The rifle frame will be a modified version of the AR-15 with a realistic feel and look. Utilizing rechargeable batteries as a power source, the rifle will be portable while having a weight similar to that of a real firearm. The laser rifle will feature a double laser system that simultaneously emits a visible light laser used for calibration and visible feedback and a 940 nm wavelength laser used for signal transmission to the target board. The IR laser will act as a transmitter and will be modulated at a standard 38 kHz carrier frequency that IR receivers in the target board will be able to interact with. The visible light laser will be toggleable such that the rifle does not waste power if the laser is no longer needed. The light emitted from the laser diodes used will be collimated through separate lenses, interact with a beam splitter, and then both will exit the barrel after passing through a beam expander.

The laser rifle will be programmed so that gunfire sounds play and recoil-simulating vibration motors activate when fired. The laser rifle will also be able to fire at variable fire rates that can be changed via software. The rifle will have a software-based magazine system and ammo counter that requires magazines to be changed after depleting all rounds in the magazine. All features will be customizable using a smartphone app that communicates with the rifle using Bluetooth.

Additionally, a camera running a live human detection algorithm will be attached using the rifle's rail system. Once a person enters the field of view of the camera, the laser diode will shut off, preventing the laser from potentially harming any passerbys. The camera will use a custom lens system to change the field of view to a desired value.

The final attachment is a night vision system using a magnified scope, LCD display, and camera. First, a rail-mounted optical rifle scope that can be used to magnify and view the target will be designed and made. The rifle scope will contain a telescoping magnification system for variable zoom. A camera using an IR viewing CMOS sensor will then be designed and mounted such that it is effectively looking through the scope like a human eye. The camera will also be removable, so the scope can be used to aim as a normal optical sight.

The camera will be hooked up to an LCD display mounted to the scope that plays live feed from the camera-scope system. Using a custom LED flashlight with a 850 nm peak wavelength, the surrounding area will be illuminated with IR light that is captured by the camera and streamed onto the display. 850 nm light typically has a low spectral sensitivity in IR receivers, and CMOS sensors have fairly good sensitivity at this wavelength. Since the amount of IR light necessary to have a clear image will be not known without testing, the flashlight will also include a telescoping lens system to change the focus of the light. Ultimately, this system can be used to view the target and fire at it by using the display to aim. An example of how this system would look after being built is shown in the figure below.

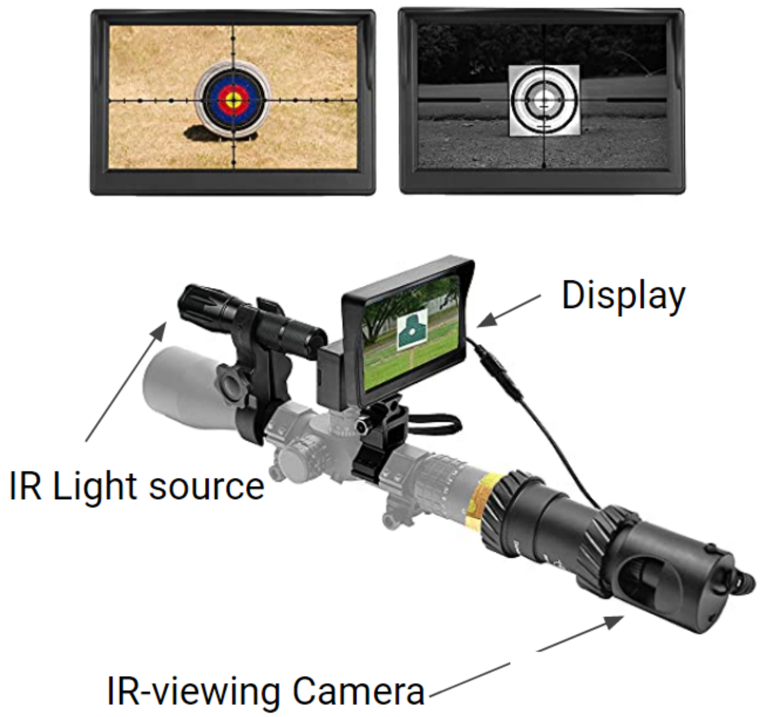

Figure 4. Night vision system

Unlike other products, this makes it possible to use our target-shooting system at night time or in low-light environments where photodetectors will work best due to low noise from other sources. Of course, a simple white light flashlight could be attached to the rifle, but using this night vision system makes it possible to use the rifle to simulate night vision training scenarios where flashlights cannot be used. In military night operations, night vision goggles are paired with rifle rail-mounted IR lasers that become visible when using the goggles. Similarly, our system will simulate this and enable the user to aim and see the IR laser in real time using the display, making the visible laser completely optional in nighttime conditions.

Target Board

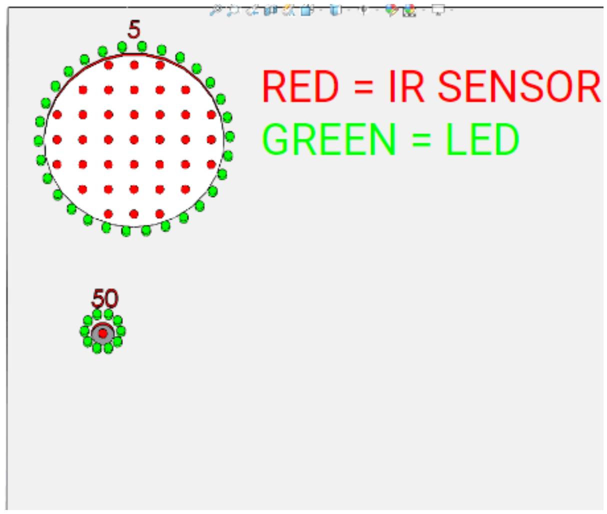

Figure 5. Target Board Front

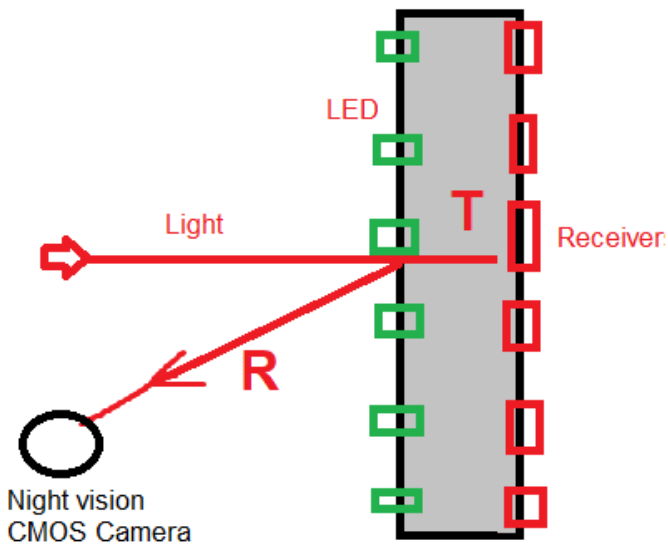

Figure 6. Target Board Cross Section

The design will be based on an arcade Skeeball hole system with targets of various sizes as shown in Figure 5. A scoring system where successfully hitting smaller targets will award a user with more points will be made. Game rules and scorekeeping will be controlled using a smartphone app connecting to the target board using Bluetooth. Using rechargeable batteries as a power source, the target board will be used to give visible feedback to where the laser was fired at using LEDs and IR receivers. Receivers were chosen over standard photodiodes and phototransistors because they are more resistant against ambient IR lighting, ideally allowing the target-shooting system to be used in broad daylight. The IR receivers, placed throughout a target circle, will be used to sense where the shot was placed and cause the surrounding LEDs to light up.

For example, in Figure 5, if a receiver in the area marked “5” captures the IR laser light, all of the LEDs surrounding the “5” circle will light up in response. The amount of receivers installed in an area will depend on the size of the area. The LEDs and receivers will be installed behind the front surface of the target board. There will be designated holes in the front surface of the board where the LEDs will emit visible light that the user will be able to see after hitting one of the receivers in an area. Unlike the LEDs, the tops of the receivers will be completely behind the target board with no holes present. Figure 6 shows this arrangement in a simplified manner. Since the board will be 3D printed, a printer filament transparent to IR light will be used to protect the receivers while also ensuring sufficient amounts of incoming light are captured.

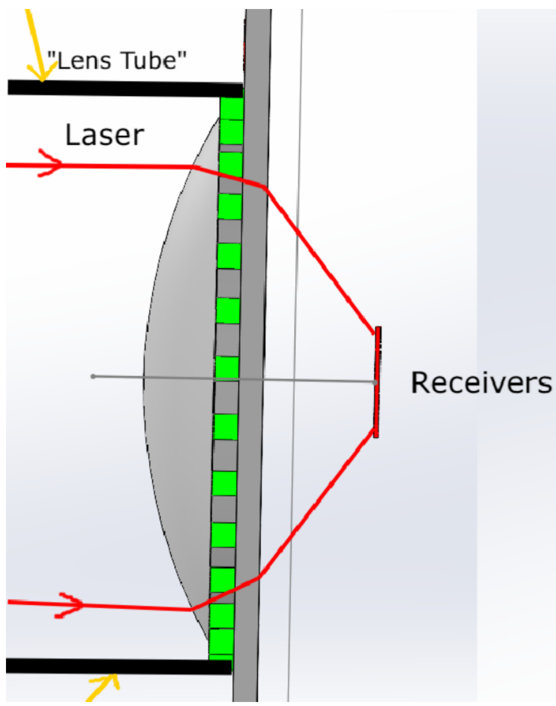

Figure 7. “Inherent Lens System” Design Concept

Since the receivers will need to be powered constantly, one way to reduce the amount of receivers in the system is by using a focusing lens as shown in Figure 7. By designing the surface of the target board such that it has spherical curvature at target areas, the board itself will begin to act like a lens and focus the IR light to a smaller area. Rather than putting receivers scattered throughout the area of the entire circle, the receivers would only need to be installed in the area where the light will be focused to, reducing the total amount of receivers needed. To reduce the amount of noise from other light sources, a light-blocking lens tube can also be implemented.

Requirements/Specifications

Requirement ID	Requirement/Specification	
1.0	The system will not exceed 10 lbs with all internal components.	5 - 10 pounds
1.1	The system will be pairable with a phone through Bluetooth and be recognized by the mobile app.	Bluetooth 5.0
1.2	The system will be powered by batteries that can be recharged with a compatible plug.	9V Lithium Battery
1.3	The system needs to perform at the shortest time interval between the pulling of the trigger and the visual response of the target.	$< 1\ second$
1.4	The system controller should use power efficiently.	Efficiency > 30%
1.5*	The system should be in “ready for use” state within a short time after startup.	$< 1\ minute$
1.6*	The system should have the controller stay running at a high uptime.	$\geq 4\ hours$
1.7*	The system should operate without overheating.	$\leq 50\ °C$
1.8	The system will include a mountable variable-zoom rifle scope with adjustable reticle.	At least 4x max magnification
1.9	The system will be able to operate at a long range distance between the rifle and target board.	>15m
1.10	The system will emit a laser beam that has low divergence such that it can be used accurately at long ranges.	<0.5 mm per meter
1.11	The system will output a laser spot size that is small enough to ensure accurate shot placement on the target board.	<20 mm at 15m target distance
1.12	The system will implement a human detection camera safety system with a narrow field of view.	<45 degrees
1.13	The system will use a 3d printed target board that is large enough to be clearly visible at long ranges.	> 12 in x 12 in

Table 1: System Requirements

**Highlighted blue section means that we can demonstrate using our group test method.*

Project Constraints and Software Standards

Constraint	Constraint Specification	
Maintenance	System maintenance, replacements, and adjustments should be easily doable	
Ease of Use and Customization	All components must fit on the rifle without reducing usability, and all attachments (scope, detector camera, flashlight) will be mountable	Picatinny rail mounting-system
IR Laser & Target Board Wavelength	The receivers used in the target board must have peak sensitivity at the rifle's IR laser wavelength	100% sensitivity at 940 nm
IR Receiver/Laser Modulation Frequency	The LEDs used in the target board should be activated only when the IR laser strikes the receivers and will remain inactive in ambient lighting	38 kHz
LED Visible Feedback	Target board LEDs must emit enough power to be clearly visible with the naked eye from long range	Visible at >15m
Laser Power	The laser rifle must emit an IR beam with power that is at low-risk of damaging human eyes	Class 3R or lower (<5 mW)
Target Board Transparency	The target board must be made using a 3D printer filament that is transparent to the designated IR laser wavelength	Clear PETG (30-50% Transmission at 940 nm depending on thickness)
Phone App Framework	React Native	Must be in Expo CLI ecosystem
Programming Language	JSX syntax extension to Javascript, and Python for programming	

Table 2: System Constraints

Block Diagrams

Hardware block diagram for our system that includes the member responsible for the design of each component as well as a software block diagram for a mobile app.

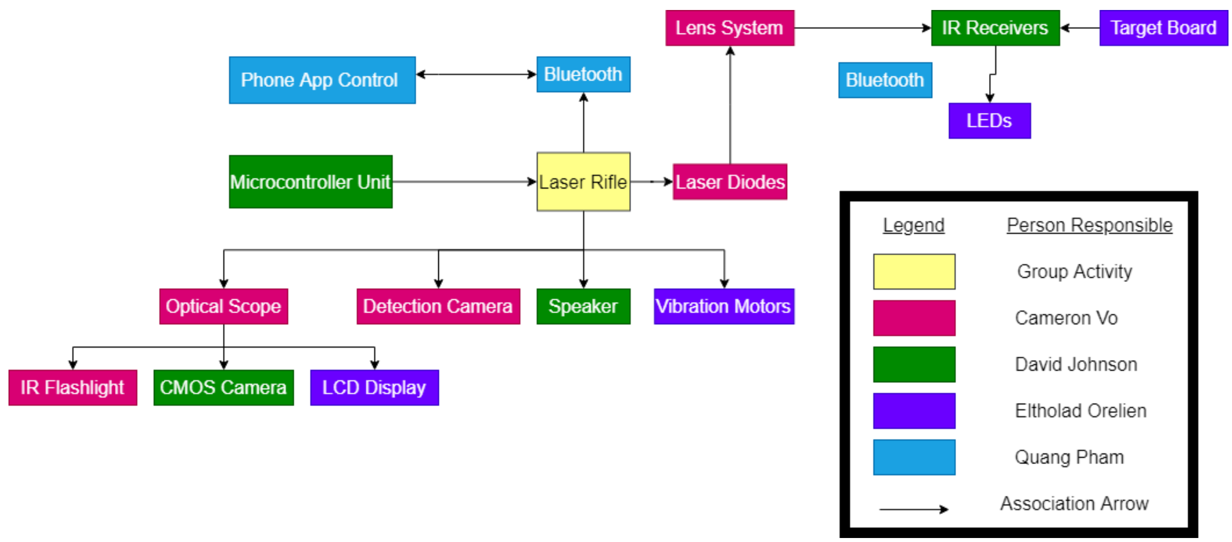

Figure 8. Laser Rifle and Target Board Block Diagram

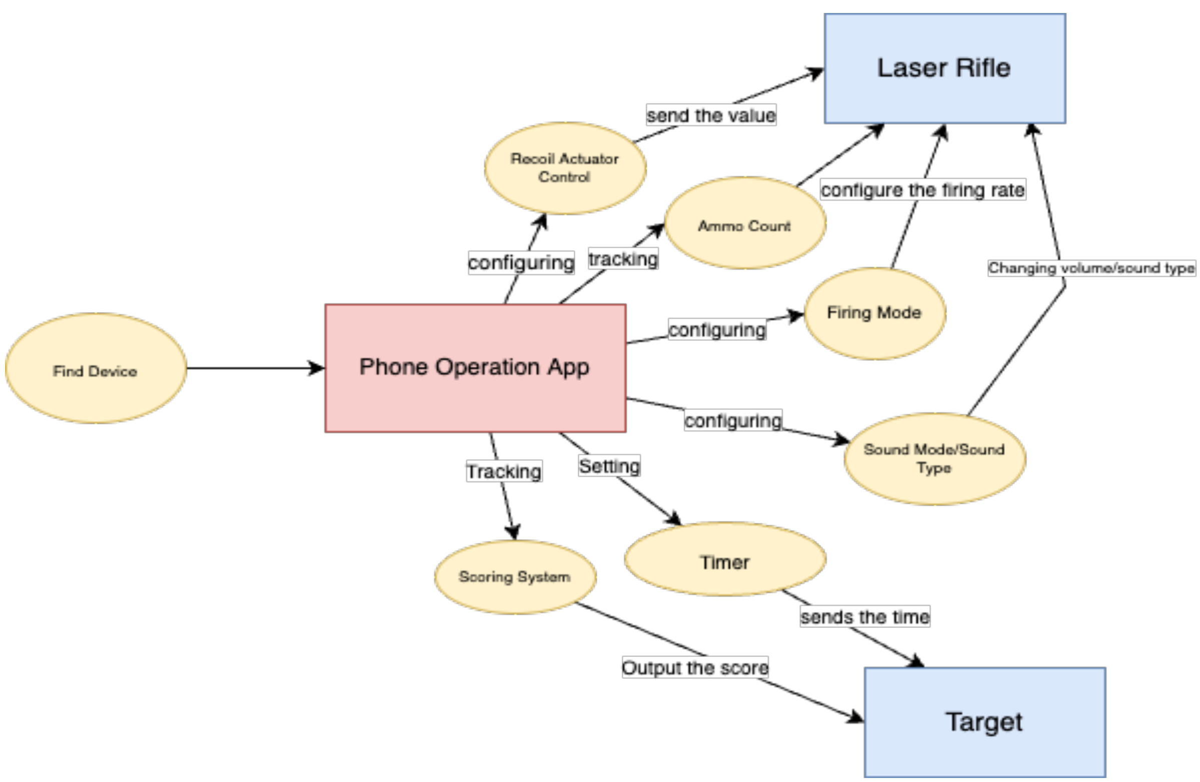

Figure 9. Mobile Phone Application Block Diagram

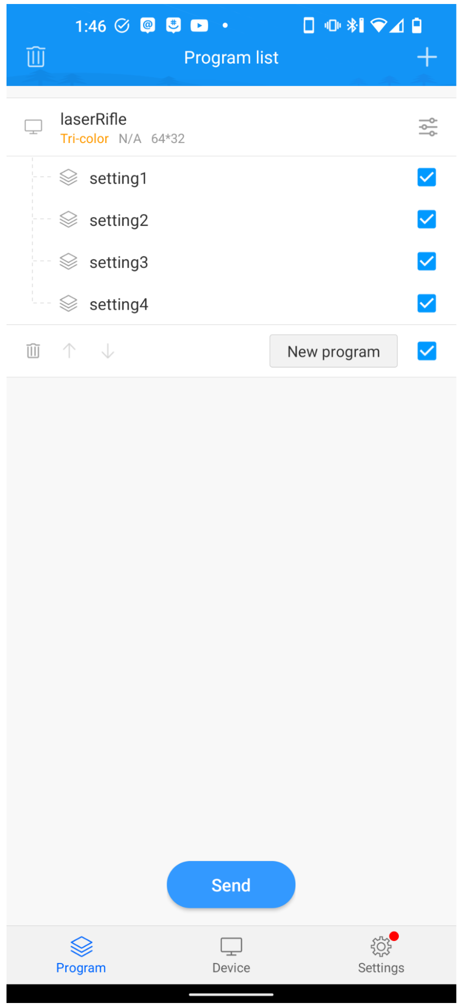

Figure 10. Mobile Operation App Prototype

The above screenshot is a concept demonstration of how settings will be configurable using our custom smartphone app. In the future, other gamemode settings such as keeping score, players, and timers plan to be added.

House of Quality

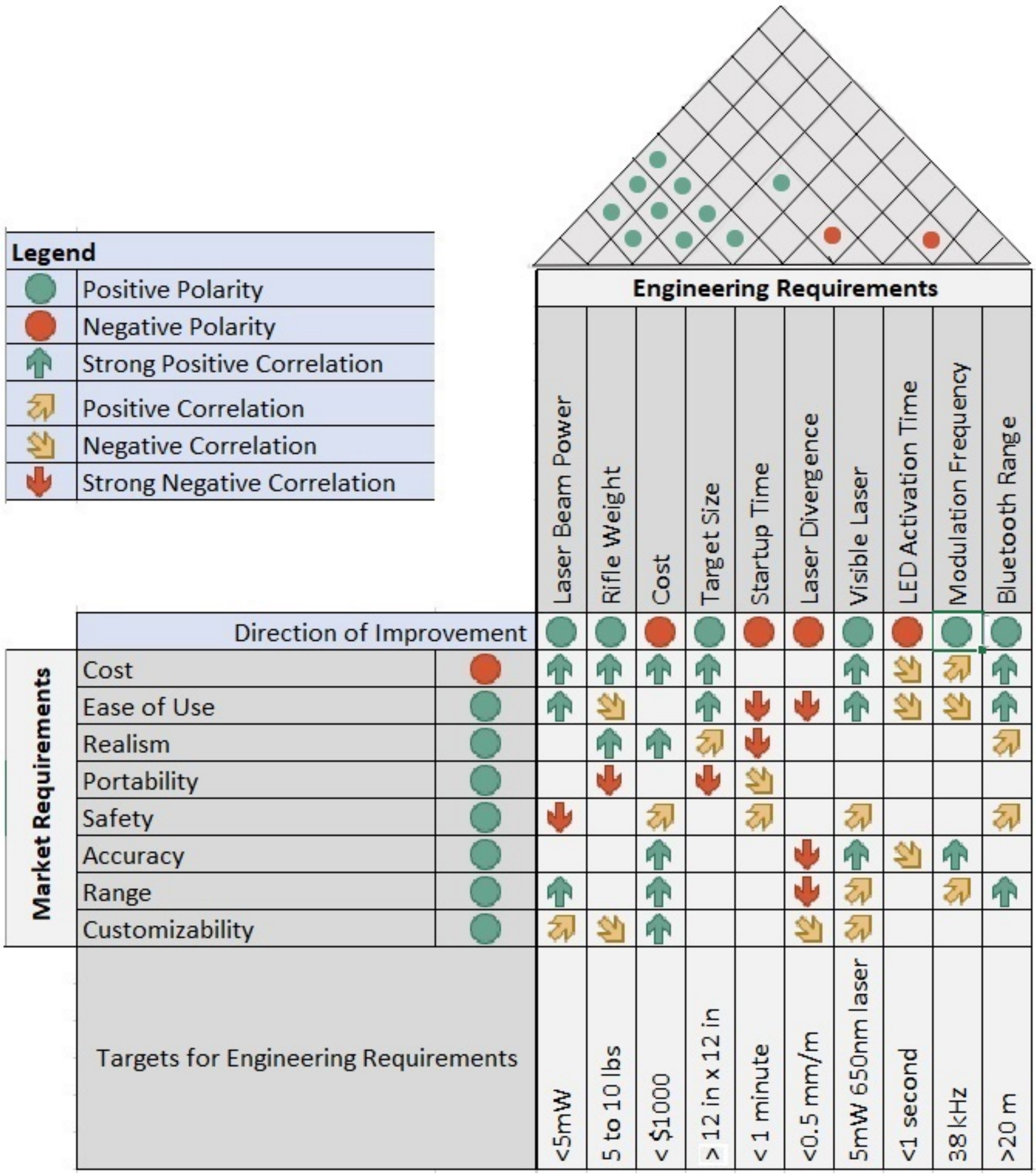

Figure 11. House of Quality

Project Financing (Estimated)

This project will be self funded by the group, with costs being split evenly among each group member. Provided is an estimated cost range for each item and an estimated minimum and maximum total cost. We will buy extra parts for testing purposes and as backups. These prices will be reflected in the finance sheet.

Part Description	Price Range
Rifle Frame	$50-75
Laser Diodes	$50-75
Lenses	$150-200
CMOS Sensors	$20-50
LCD Display	$10-30
LEDs	$20-40
3D Printer Filament (Frame for Target Board and Rifle Attachments)	$100-150
IR Receivers	$20-40
Battery for Rifle	$15-30
Battery for Target Board	$15-30
Speaker	$5-10
Microcontroller Units (PCB)	$40-70
Vibration Motors	$10
Breadboard	$10
Misc Components	$40
Minimum	**$505**
Maximum	**$860**

Table 3. Estimated Cost Analysis

Initial Project Milestones

Project deliverables are shown in the table below for the Fall 2022 semester. The table will be updated as deliverables are completed.

Task	Start	End	Status
Early Stage/Bootcamp			
Form Groups	**8/23/22**	**8/30/22**	**Complete**
Discuss Project Idea	**8/30/22**	**9/1/22**	**Complete**
Decide Meeting Schedule	**9/1/22**	**9/1/22**	**Complete**
Divide and Conquer 1.0 9/16			
Finalize Project Idea choice	**9/1/22**	**9/6/22**	**Complete**
Determine Budget	**9/6/22**	**9/12/22**	**Complete**
Hardware Diagram	**9/6/22**	**9/13/22**	**Complete**
Determine Objectives	**9/6/22**	**9/13/22**	**Complete**

Determine Standards	**9/6/22**	**9/13/22**	**Complete**
Determine Specifications	**9/6/22**	**9/12/22**	**Complete**
Divide and Conquer 2.0 9/30			
Group 6 DCV1 Meeting	**9/21/22**		**Complete**
Refine Goals, Constraints and Standards	**9/21/22**	**9/30/22**	**To Do**
Apply changes discussed in DCV1 Meeting	**9/21/22**	**9/30/22**	**To Do**
Create House of Quality	**9/21/22**	**9/30/22**	**To Do**
60 Page Draft Document 11/4			
Research and Document work	**9/30/22**	**11/4/22**	**To Do**
Refine Requirements, Constraints and Standards	**9/30/22**	**11/4/22**	**To Do**
Create Hardware Schematic	**9/30/22**	**11/4/22**	**To Do**
Create Hardware Testing Plan	**9/30/22**	**11/4/22**	**To Do**
Create Software Testing Plan	**9/30/22**	**11/4/22**	**To Do**

Design Mobile App	**9/30/22**	**11/4/22**	**To Do**
Wireless Considerations	**9/30/22**	**11/4/22**	**To Do**
Software to Hardware Integration Plan	**9/30/22**	**11/4/22**	**To Do**
Select Parts	**9/30/22**	**11/4/22**	**To Do**
Order Parts	**9/30/22**	**11/4/22**	**To Do**
100 Page Draft 11/18			
Parts Testing and documentation	**11/4/22**	**11/18/22**	**To Do**
Hardware Prototype Assembly Plan	**11/4/22**	**11/18/22**	**To Do**
Software Prototype Assembly Plan	**11/4/22**	**11/18/22**	**To Do**
Final Document 12/6			
Build and Test Hardware Prototype	**11/4/22**	**11/18/22**	**To Do**
Build and Test Software Prototype	**11/4/22**	**11/18/22**	**To Do**

Table 4. Project Milestones

Features Under Consideration

- Ability to switch firing mode (semi auto, burst, automatic, & spread)
- Different game varieties to be added within a phone application
- Ability to cycle through games with display on gun
- Ability to modify recoil intensity to simulate different gun variants
- Remaining ammo capacity on the gun display
- Infrared sensors determining shot distance
- Variable laser spot size
- Other types of optics (red dot or holographic sight)