Laser Target-Shooting

Group 6

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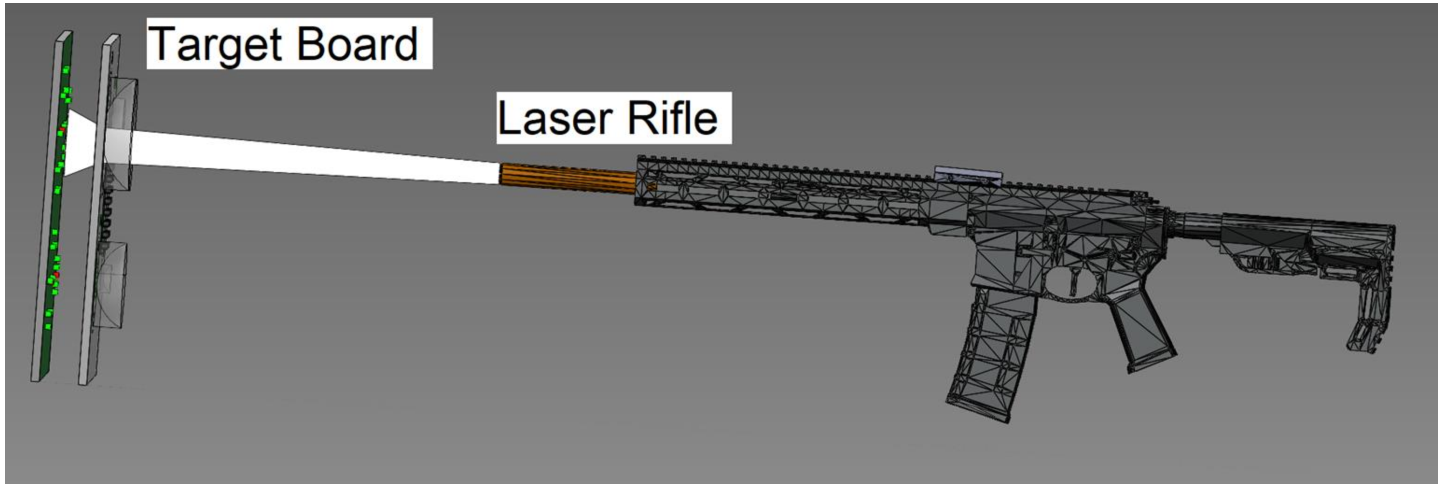
Motivation

- Live Firearms
  - Expensive, inconvenient, dangerous, and harmful for the environment
- Airsoft
  - Quite expensive and still harm the environment
  - Lack some features of real guns such as recoil
- Lasers
  - Decreased danger, environmental impact, and ammunition cost
  - Portability and accessibility increased

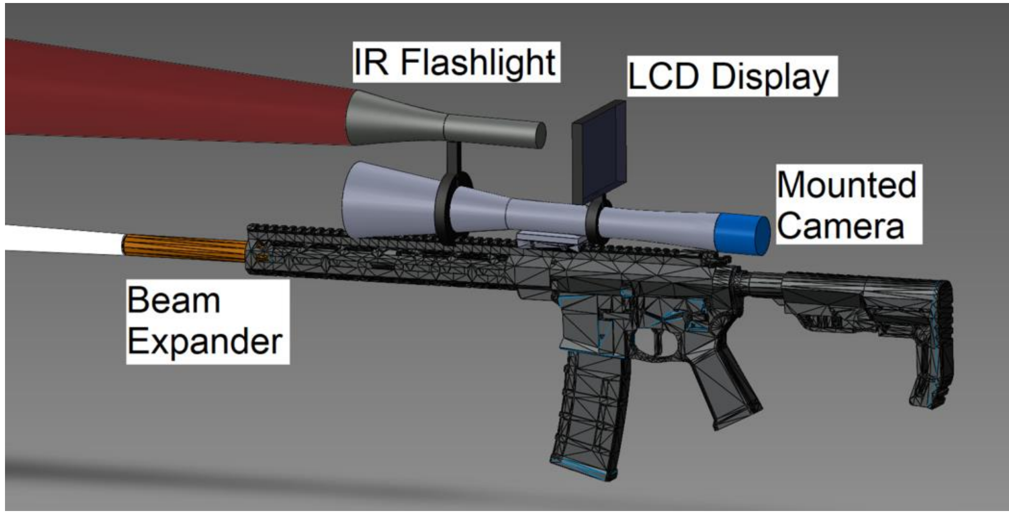
Goals

- Create a laser-target shooting system that gives immediate feedback to where a shot is made via LEDs
- Portable system usable in both broad daylight and nighttime
- Implement features to simulate real firearms (recoil, gunfire, etc)
- Develop smartphone app to control system for customizability



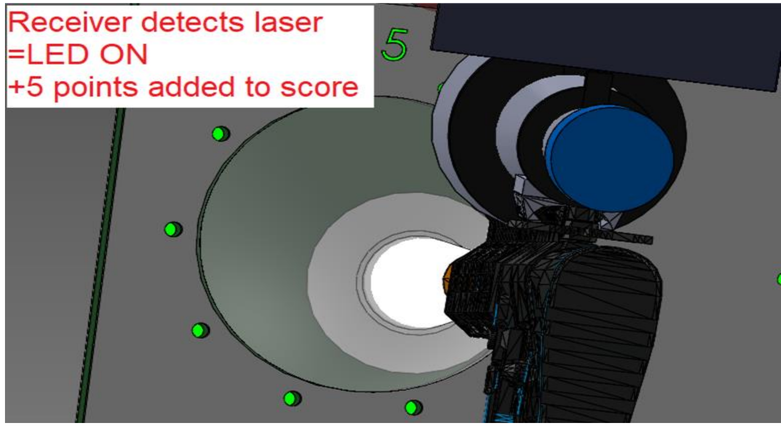
Objectives - Rifle

- Frequency modulated IR laser diode
  - Spot size and divergence angle controlled by beam expander
- Battery-powered
- Rifle Scope
  - Mountable Night Vision System
    - IR Flashlight, CMOS Camera, LCD Display
- Pairs to smartphone app via Bluetooth
  - Customization of features i.e. gunfire sounds
  - Software-based magazine and ammo system



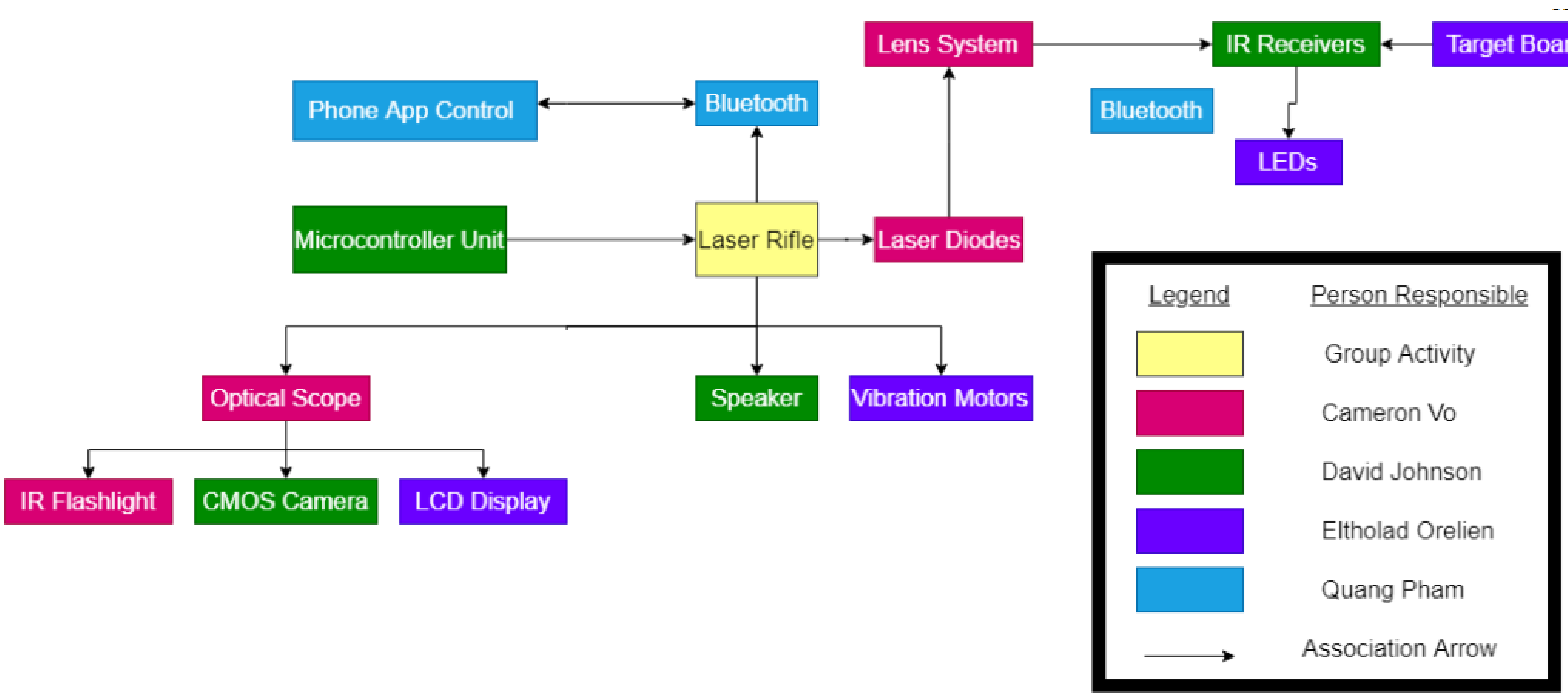
Objectives - Target Board

- IR Receivers
  - Only detects modulated light at the IR laser frequency
- LEDs
  - Lights up when the laser is detected by a receiver
- Built-in Concave Lenses
  - Reduce optical and thermal noise and expand the beam further
- Pairs to smartphone app with Bluetooth
  - Keeps track of score and used for setting up systems

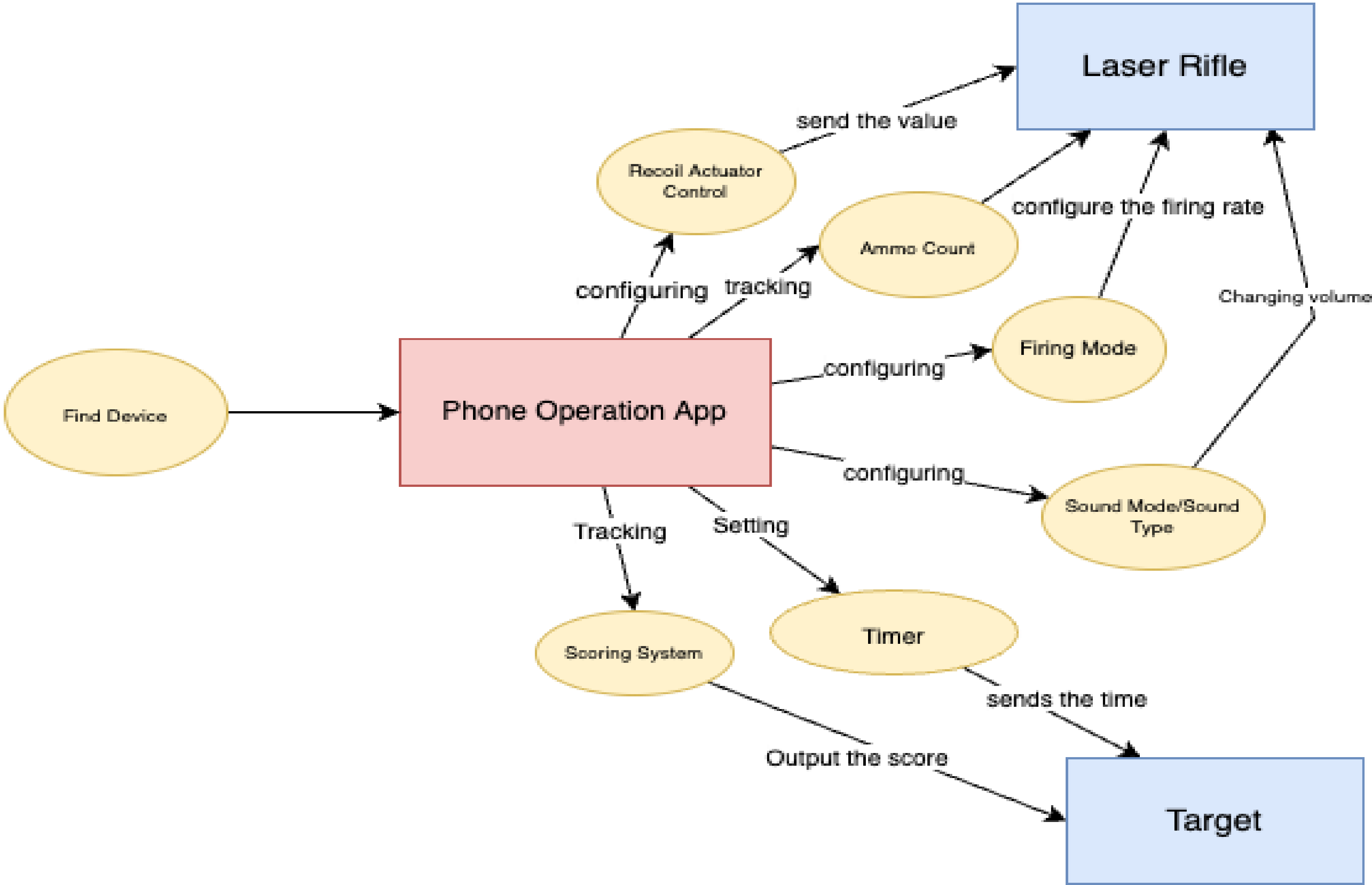


Requirement ID	Requirement/Specification	
1.0	The system will not exceed 10 lbs with all internal components.	5 - 10 pounds
1.1	The system will be pairable with a phone through Bluetooth and be recognized by the mobile app.	Bluetooth 5.0 or Bluetooth Low Energy
1.2	The system will be powered by batteries that can be recharged with a compatible plug.	9V Lithium Battery(s)
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 laser target shooting system idle power should be low.	Rifle- 1Wh Target- 0.5Wh
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.	> 4 hours
1.7	The system should operate without overheating.	< 50 °C
1.8	The system will include a mountable rifle scope with high resolving power	> 3.5x magnification <0.15 mrad angular resolution
1.9	**The system will be able to fully function at a long 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.	<1.5 mm per meter (1.5 mrad)
1.11	The system will output a laser spot size that is small enough to ensure accurate shot placement on the target board.	<40 mm at 15m target distance
1.12	The system will emit a laser beam that is considered low-risk for eye safety.	Class 3R (<5 mW)
1.13	The system will use a 3D printed target board that is large enough to be clearly visible at long ranges while also being portable	> 200mm x 200mm < 10 lbs

Hardware Block Diagram



Software Block Diagram



Software Design Tools: Mobile Application

Figma

Tools	Features
Figma	Multiple devices screen size
Arduino IDE	built-in libraries and example codes. Open source.
Visual Studio Code	Built-in support for development applications. Great extensions to customize the edit-build-debug experience.
React Native Framework	Open source, reusability components, similar structures to React JS

Software Design Approach and Implementation

Technologies	Supported Operating Systems	Features	Coding Language	Cost
Flutter	Android & iOS	Open source, multi-platform, rich widgets	Dart	Free
React Native	Android & iOS	Open Source, and multi-platform. Reusable components	Javascript, Typescript	Free
XCode	iOS	Easy to learn Syntax, native on Apple platform, and Open source.	Swift	Free
Android Studio	Android	Open source, native on Android platform, and well optimized for Android apps.	Java, Kotlin	Free

Rifle Design Approach and Implementation

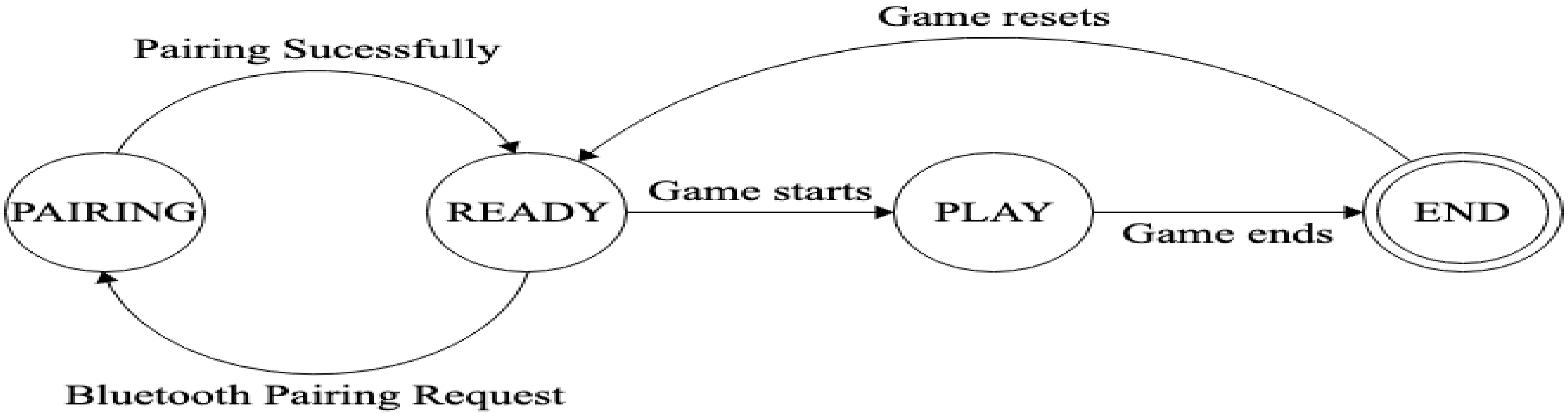
- Rifle serves as the main device for users
- User interface and system control is done through mobile app
- Additional Subsystems:
  - 2 main buttons (reload & trigger)
  - Laser Diode
  - Haptic feedback

Target Design Approach and Implementation

- Similar hardware approach to reduce complexity
  - MCU, audio and power
- Targets are slightly more passive elements
- Mostly responds to game coordination commands from Controller
- Additional Subsystems
  - IR receiver / Laser Detection
  - LED target indication

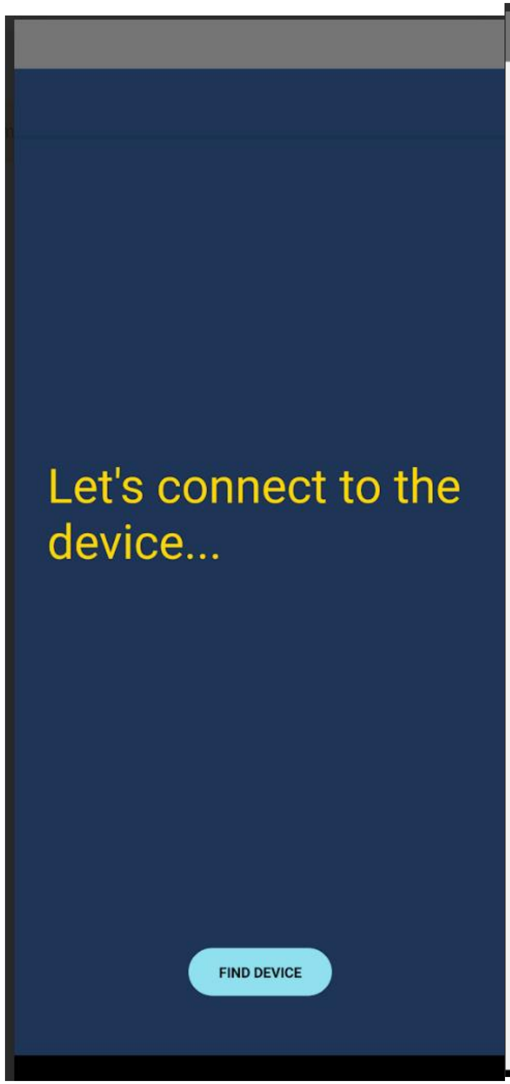
System Features Design

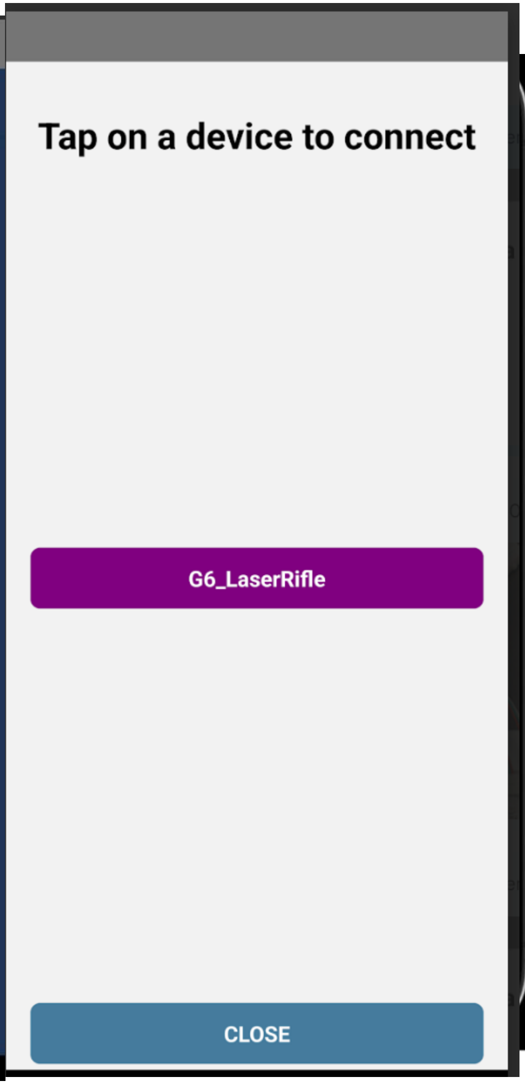
- The system will be event-based.
  Using a Finite State Machine for illustration:

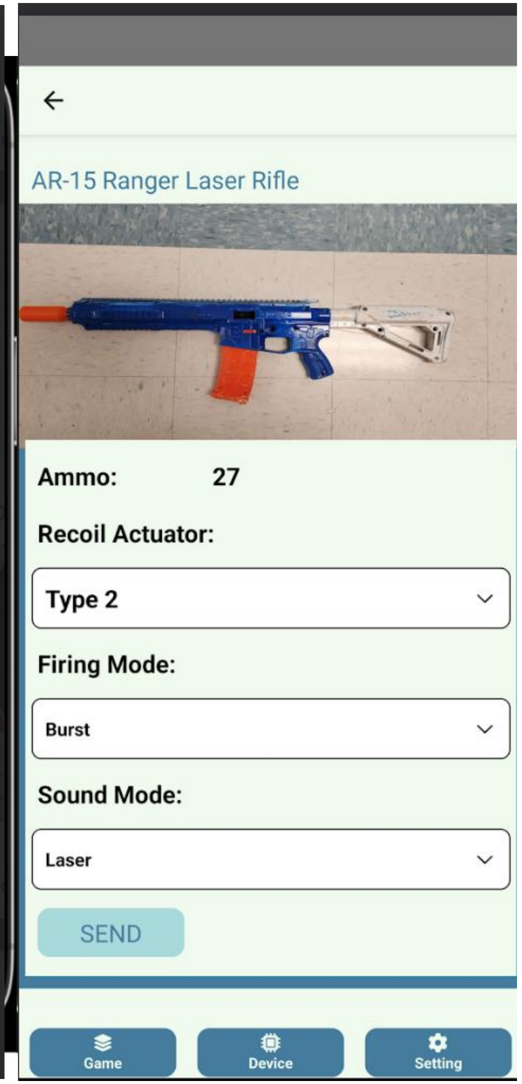


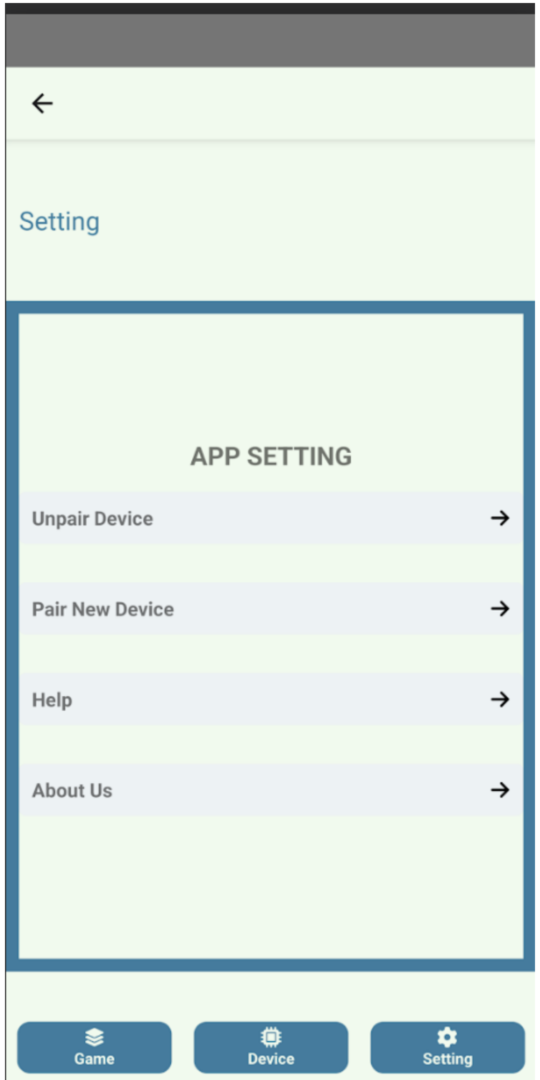
Laser Rifle and Target Board MCU State Machine Diagram

Mobile Application User Interface Design









Bluetooth Connectivity

- Bluetooth 4.0 / Bluetooth LE
  - Less power consumption
  - Single device
  - Maximum range 200 ft and 25 mbit/s speed

Microcontroller Requirements

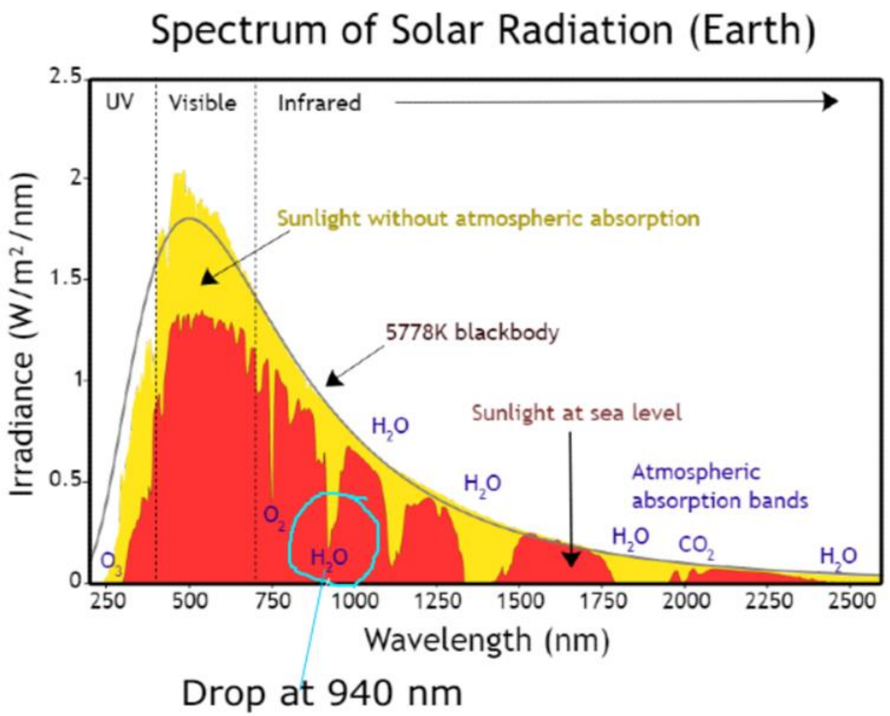
- Bluetooth functionality
- $\geq$ 20 GPIO Pin connections
- Clock Speed $\geq$ 50 MHz
- Low power / power saving mode

Microcontroller Selection

Company	Arduino	Texas Instruments	Espressif Systems
Microprocessor	ATmega2560	MSP-EXP430G2	ESP32-WROOM-32-N4
Operating Voltage (V)	5V	1.8V – 3.6V	2.7V – 3.6V
Current Draw (mA)	40	1	500
Bluetooth (Stock)	No	No	Yes
Wi-Fi (Stock)	No	No	Yes
Clock Speed	16 MHz	16 MHz	80 - 240 MHz
Availability	Available/Own	Available/Own	Available/Own

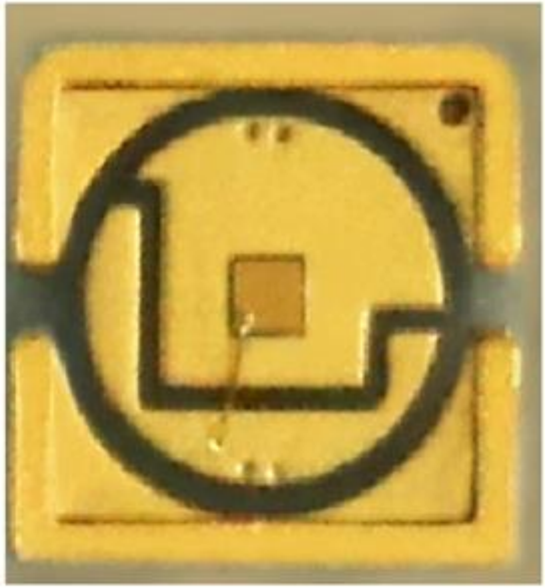
Wavelength Selection

- In deciding wavelength, we considered the:
  - Least amount of optical noise
  - Compatibility with commercial photodetectors
  - Ability to find low-power laser diodes
  - Cost of related components
- We chose 940 nm as the wavelength



Laser Diode Selection

- There are not many low-power 940 nm laser diodes available
- RPMC Laser VD-0940C-008M-1C-410 ($13 each)
  - 940nm 8mW VCSEL diode
  - 3.5mm x 3.5mm x 3.5mm in size
  - Built-in Collimating lens (<10 mrad divergence angle)
- Since laser power must be <5mW, we used:
  - Uncoated lenses for beam expander
  - Apertures
    - Reduces spot size for more accuracy while cutting optical power



Photodetector Selection

- We chose to use IR receivers, which are photodiodes that:
  - Only detect modulated light
    - Effective countermeasure against optical noise
  - Output a digital voltage signal upon receiving signal
- VS1838B IR receivers ($0.05 each)
  - Reacts to 940nm light modulated at 38 kHz frequency
  - Outputs 0.3V signal in response
  - Low supply current (500 uA idle)

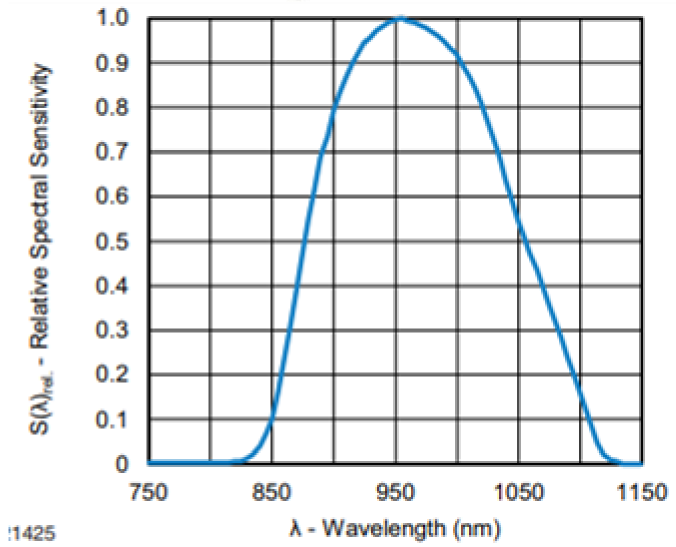
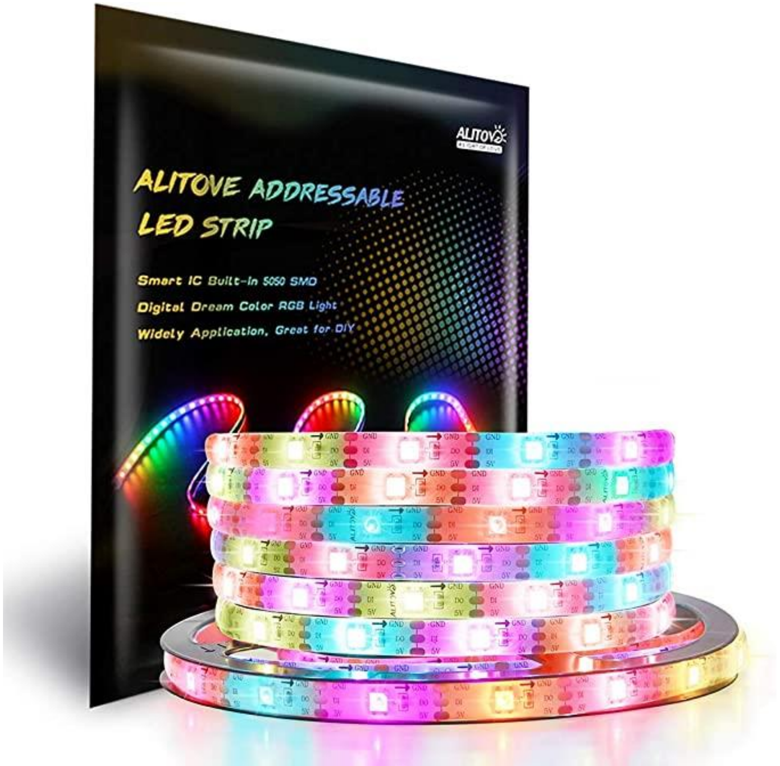


Fig. 10 - Relative Spectral Sensitivity vs. Wavelength

Target Board LED Selection

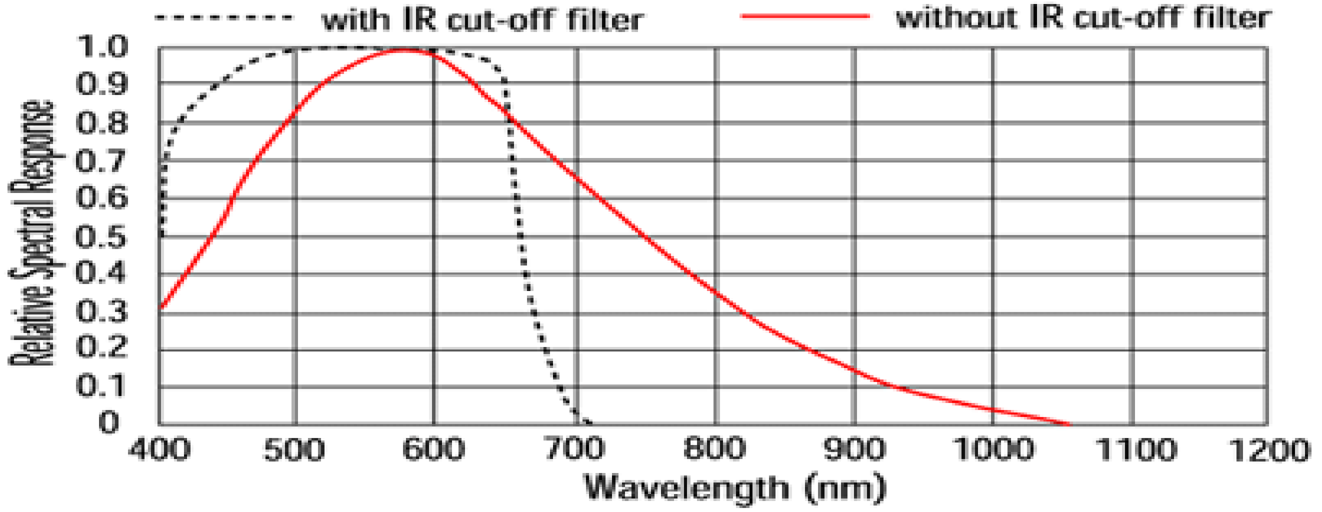
- We chose to use LED strips placed on the target board
- ALITOVE WS2812B LED Strip ($24)
  - 5V
  - Programmable



IR Flashlight LED Selection

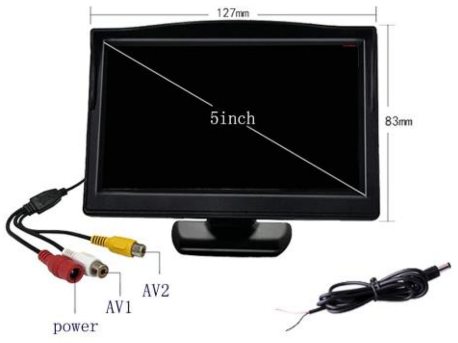
- Only needed to worry about the optical power and wavelength
  - Flashlight lens system will change the angle of the light
  - Wavelength must be detectable by CMOS camera
- Osram Opto SFH 4555 ($0.49)
  - 860 nm Through Hole LED
  - 550mW/sr @ 100mA

CMOS Spectral Sensitivity



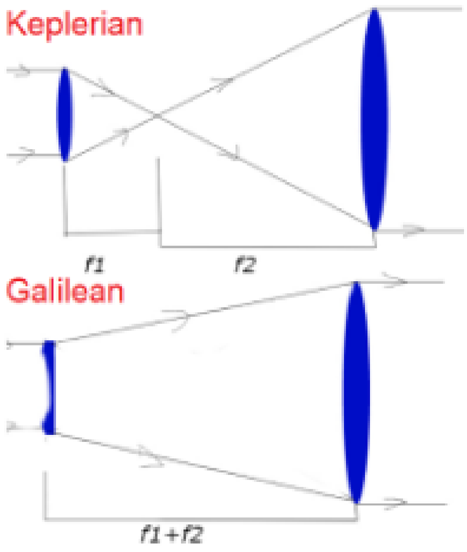
CMOS Camera and LCD Display

- We used analog video transmission
  - Digital requires extra computing device (Raspberry Pi) just to send video
- Needed best image quality, no IR filter, and good light gathering
- PixelMan PMD2A Camera ($40)
  - F/1.4 lens system and 1/2.7 inch color CMOS designed for low-light
  - 1080p with 170 degree FOV
- Padarsey 5 inch TFT LCD Color Monitor ($25)



Beam Expander

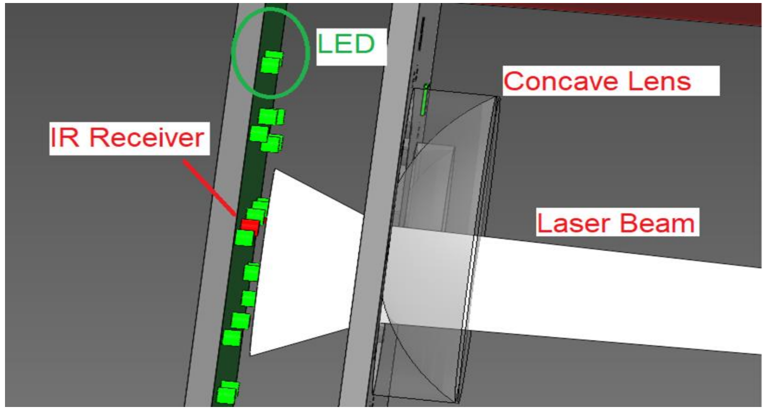
- Increases the spot size of the laser
- Decreases the divergence angle of the collimated beam
  - The smaller the angle, the longer the range the rifle can be used
- Galilean beam expander
  - Less space than using two positive lenses (Keplerian)
  - -25 EFL biconcave and 200 EFL biconvex
    - 8x Spot size increase and 87.5% decrease in divergence angle



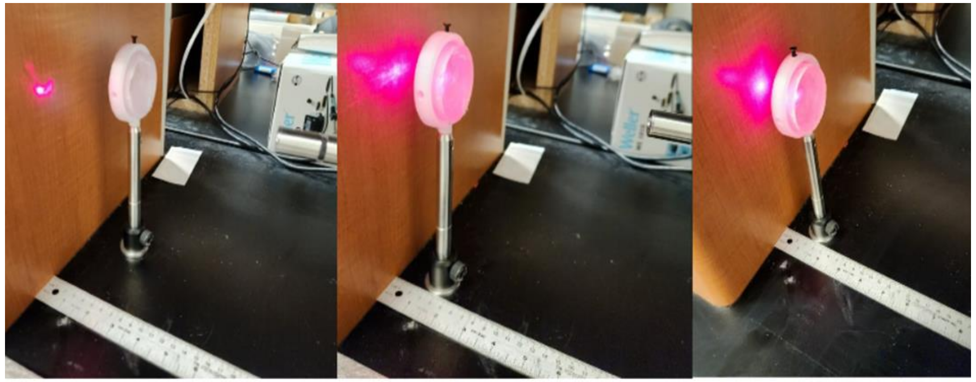
Target Board Lens System

- 3D Printed PETG Plano-concave lenses
  - Expands all incoming light through refraction and scattering
    - Significantly reduces optical noise
    - Laser beam expands, reducing amount of IR receivers needed in a target area

Concept



Testing

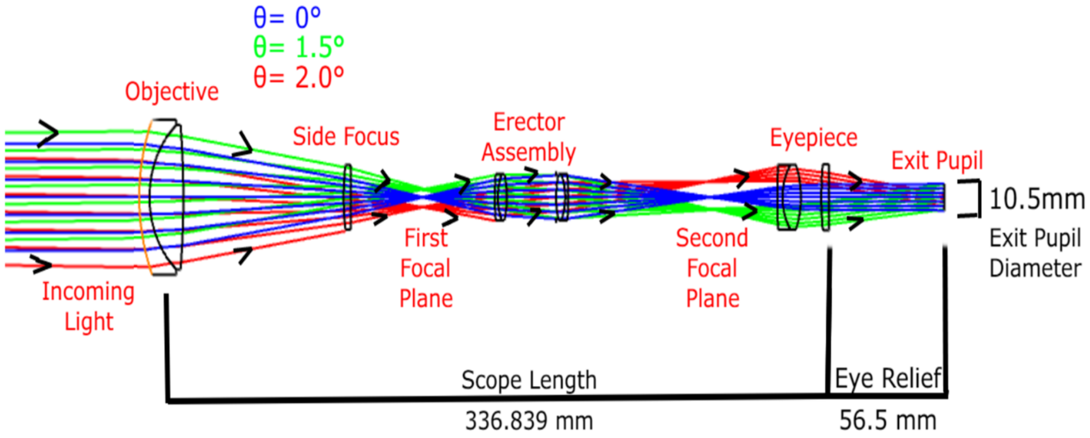


Beam | Unprocessed Lens | Processed Lens

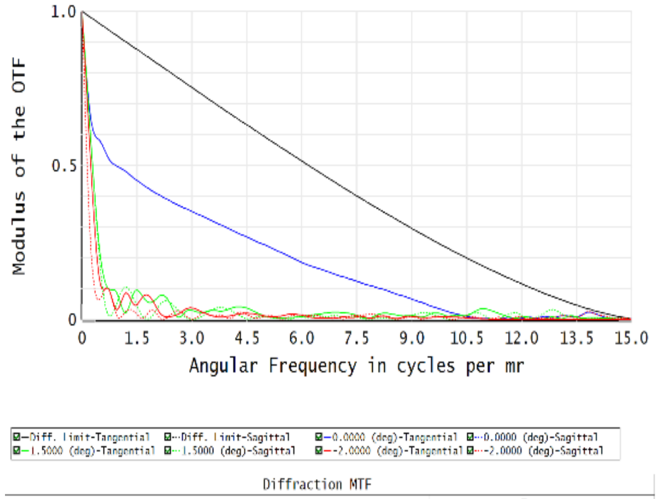
Rifle Scope

- 6 lenses total, 4 achromatic doublets
- Collimated and aberration corrected with 4x magnification
  - Zemax angular resolution is 0.125 mrad
    - Experimentally tested to be 0.135 mrad
  - Light Transmission measured at ~80%

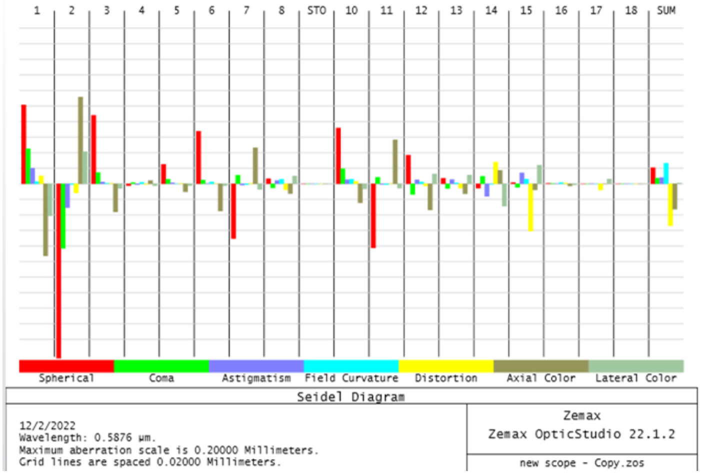
Zemax Simulation



MTF



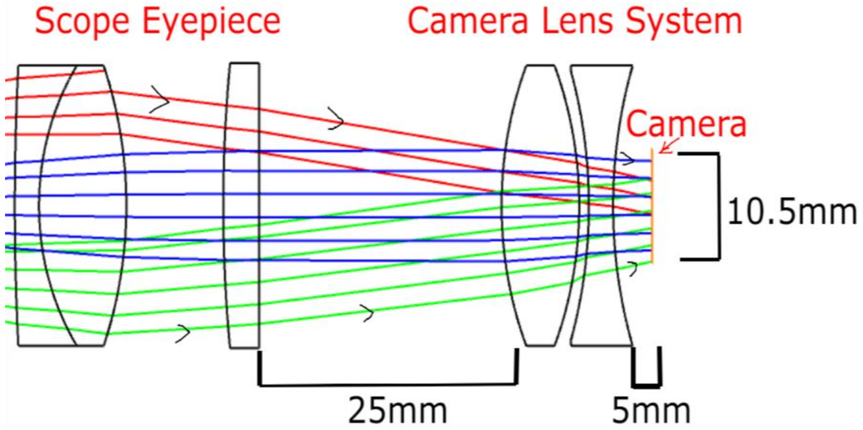
Aberration Chart



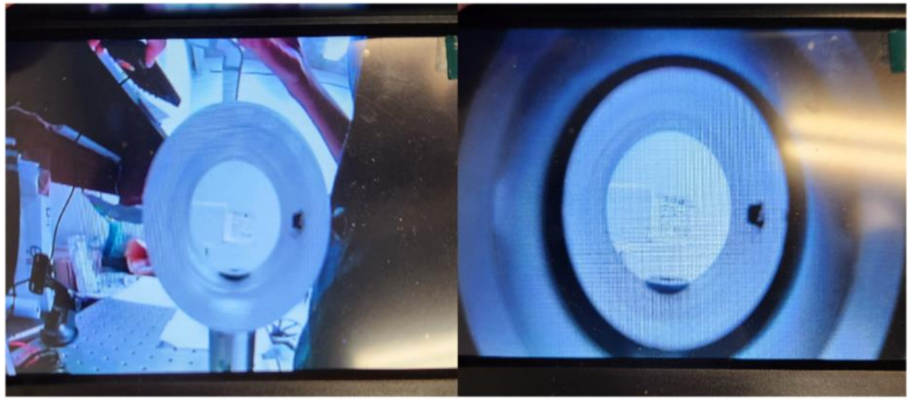
Camera FOV Lens System

- Default Camera FOV is 170 degrees
  - Much of the image is wasted showing interior of scope rather than image
- 25mm EFL combined with -25mm EFL lens
  - Magnifies image while decreasing FOV to 110 degrees
    - Not great, but decreasing FOV too much degrades image quality

Zemax Simulation



Testing



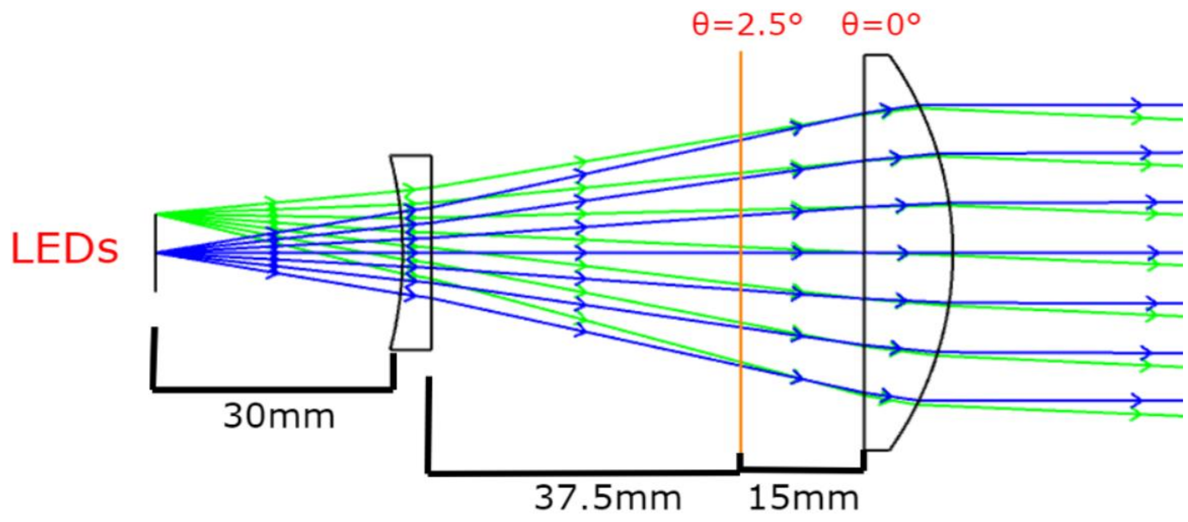
No Camera FOV Lens System

With Camera FOV Lens System

Variable Focus IR Flashlight

- Planoconcave combined with planoconvex lens
  - Compact design
    - Max axial length is 82.5mm
  - Planoconvex lens can move 15mm to adjust divergence half-angle (0-2.5 deg)

Zemax Simulation



Battery Selection

- Rechargeable 9.6VDC - NiMH ($17)
- 2000 mAh
- Common Mini-Tamiya connector type
- To be regulated to 5V and 3V for MCU and main components

Advantages:

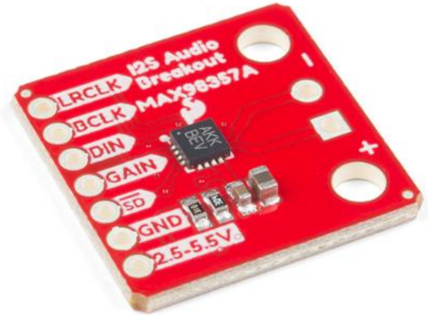
- Availability
- Cost
- Dimensions are optimal for rifle frame
- Battery Protections

Voltage Regulator Selection

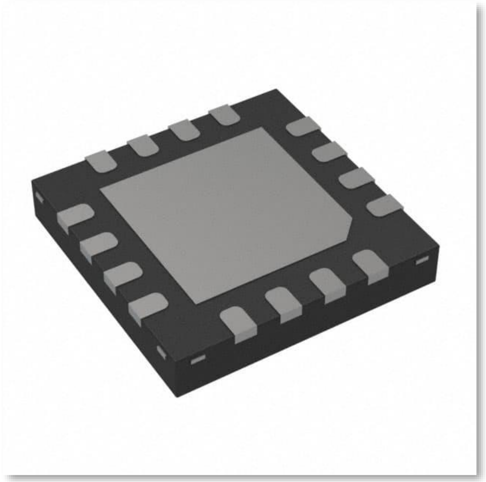
- Regulators used UA78M and L7805CDT-TR
  - Laser rifle and Target board will contain both regulators 5V

Model	Nominal Vout (V)	Output current (mA)	Price
TPS76333	1.6 - 5V Variable	800	$0.71
UAM78 33CDCY	3.3V	500	$1.36
UA78M05IKVURG3	5v	500	$0.91
TL2575-05IKTTRG3	5V	1A	$1.32

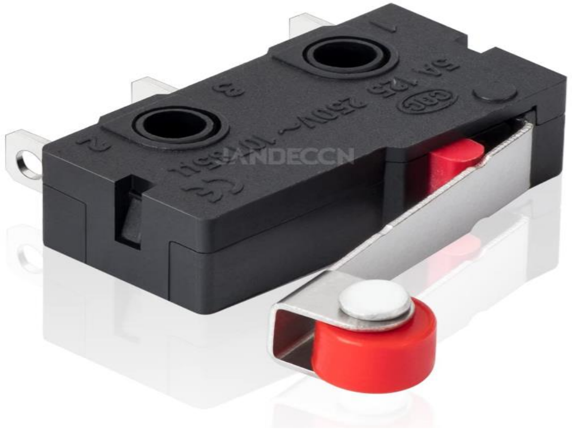
Audio Selection



- Audio Amplifier Chip
  - SparkFun I2S Audio Breakout - MAX98357A
  - The gain of the amplifier can be configured from as low as +3dB to as high as +15dB
- Speakers
  - Chip required maximum power 3.2 Watt and rated impedance of 4Ω
  - Found MakerHawk 4Ω 3-Watt Speaker



Trigger & Vibration Motor



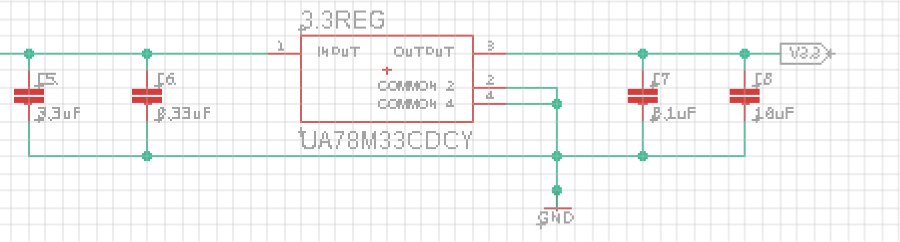
Vibration Motor

- 5V Parallax Vibration Motor 28821
- Activated by MCU when trigger is pulled

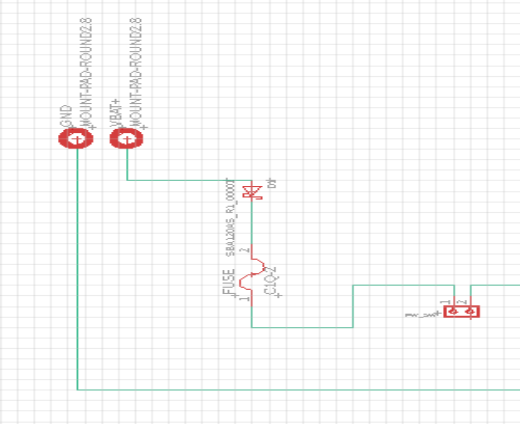
Trigger

- JANDECCN Limit Switch SPDT Hinge Roller Lever
- Used as the laser activation signal and reload function

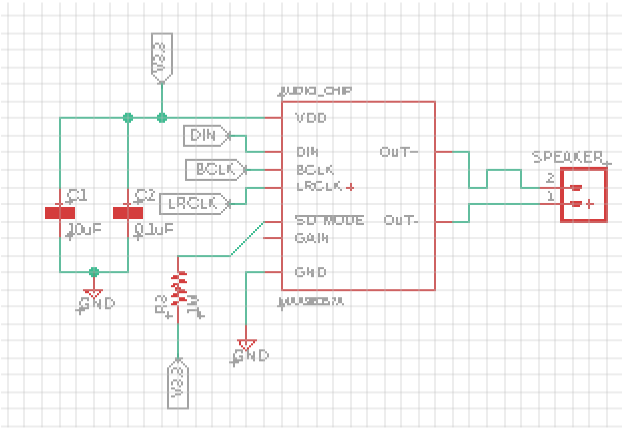
Target Schematics



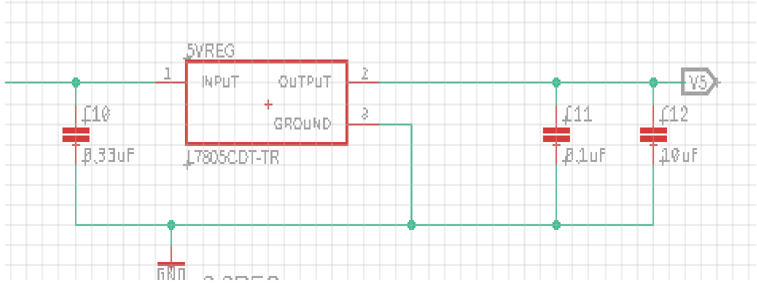
3.3V Regulator x2



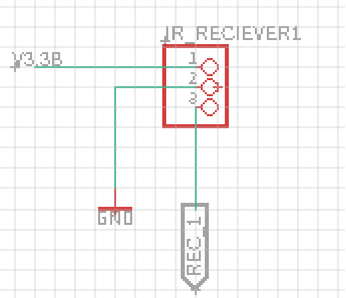
Battery & On/Off



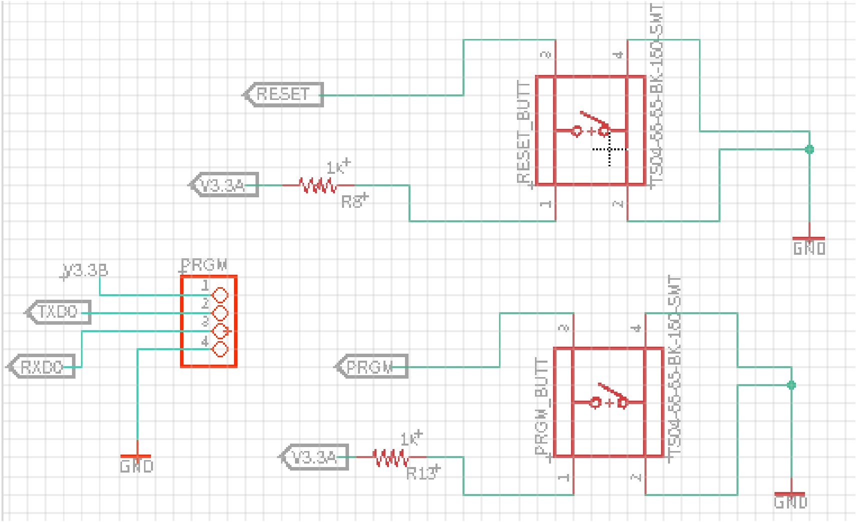
Audio Chip



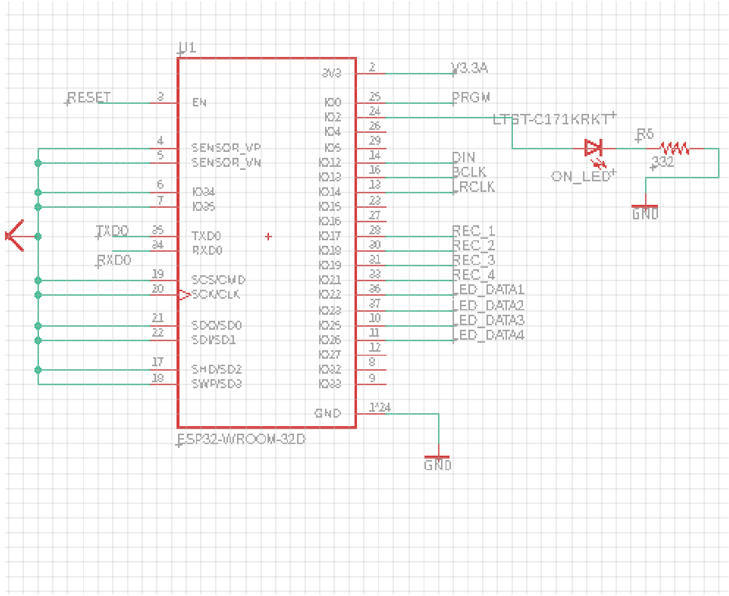
5V Regulator



IR Receivers & Pins

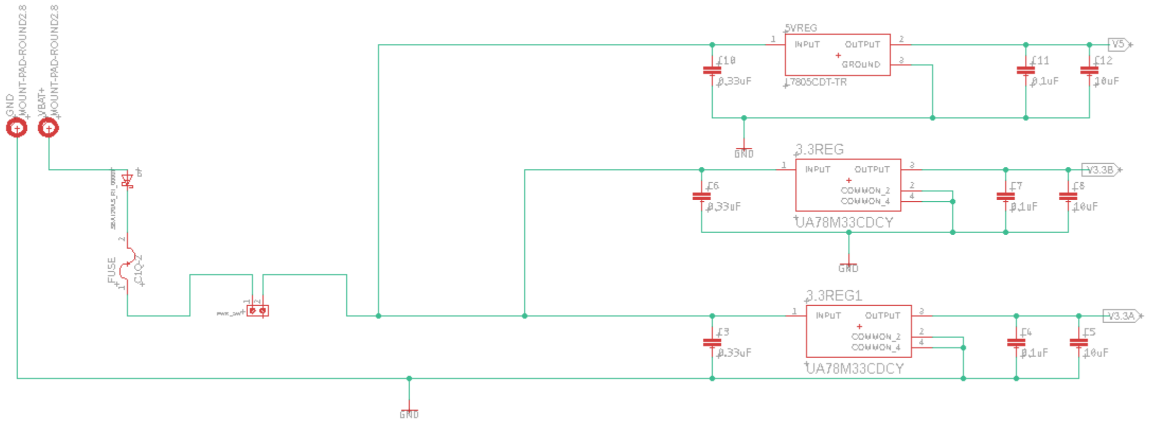


Programming Buttons/Pins

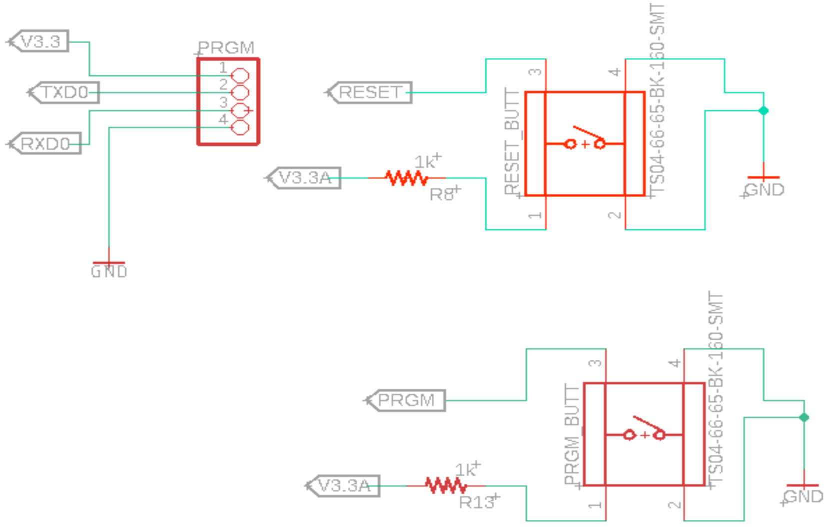


ESP32 w/Connections

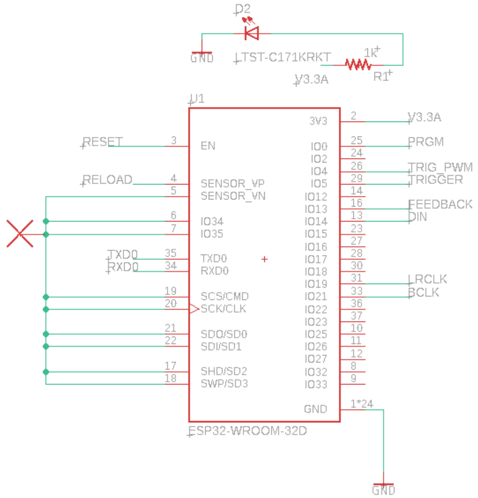
Rifle Schematics



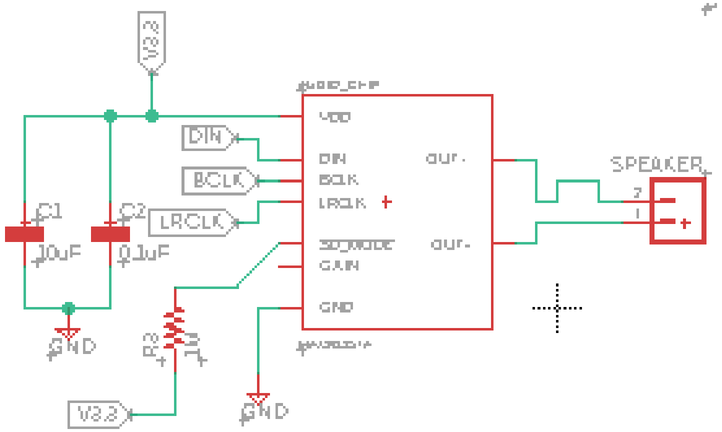
Battery connection/Switch & Regulators



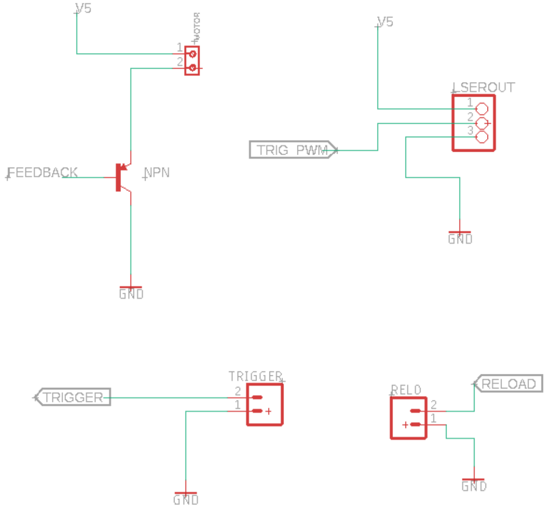
Programming Buttons & Pins



ESP32 & Pin connections

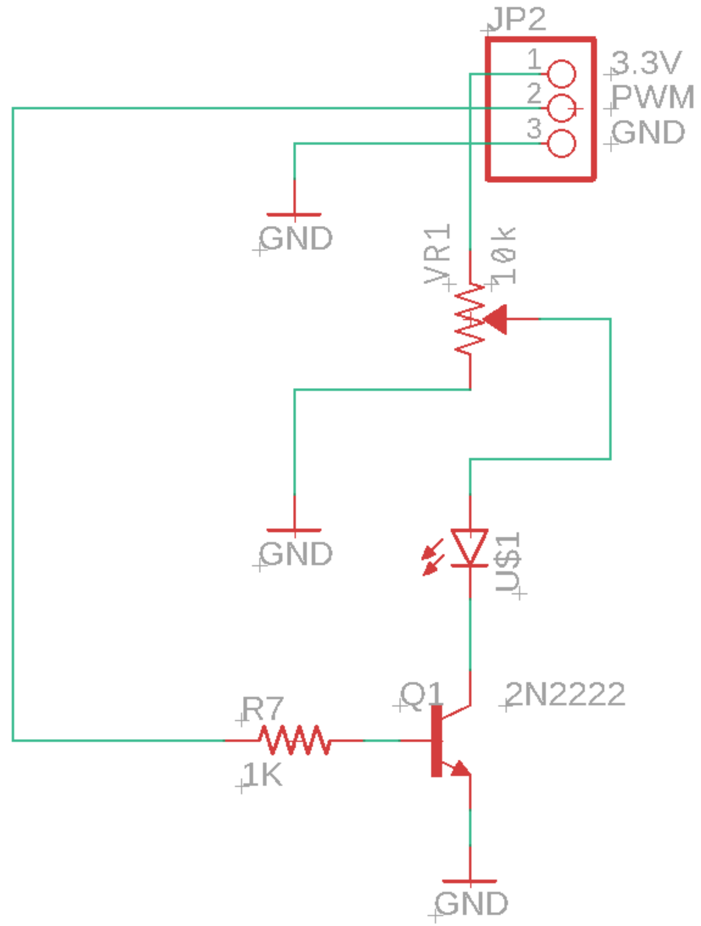


Audio Chip and Speaker

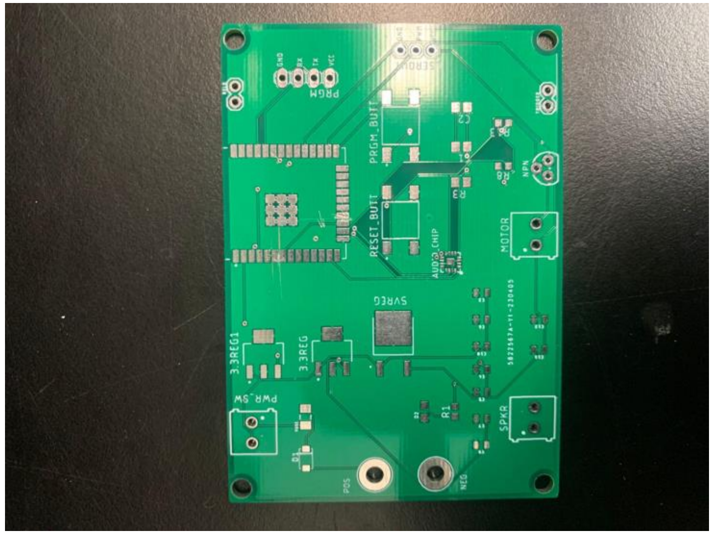


Laser, Trigger, Reload and Vibration Motor

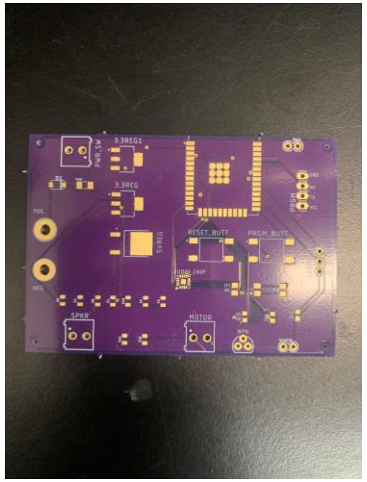
Laser Board Schematic



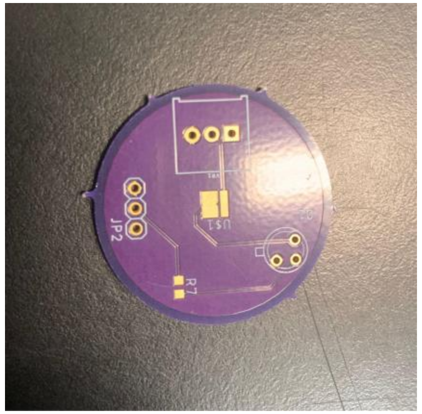
Laser Schematic



Rifle board

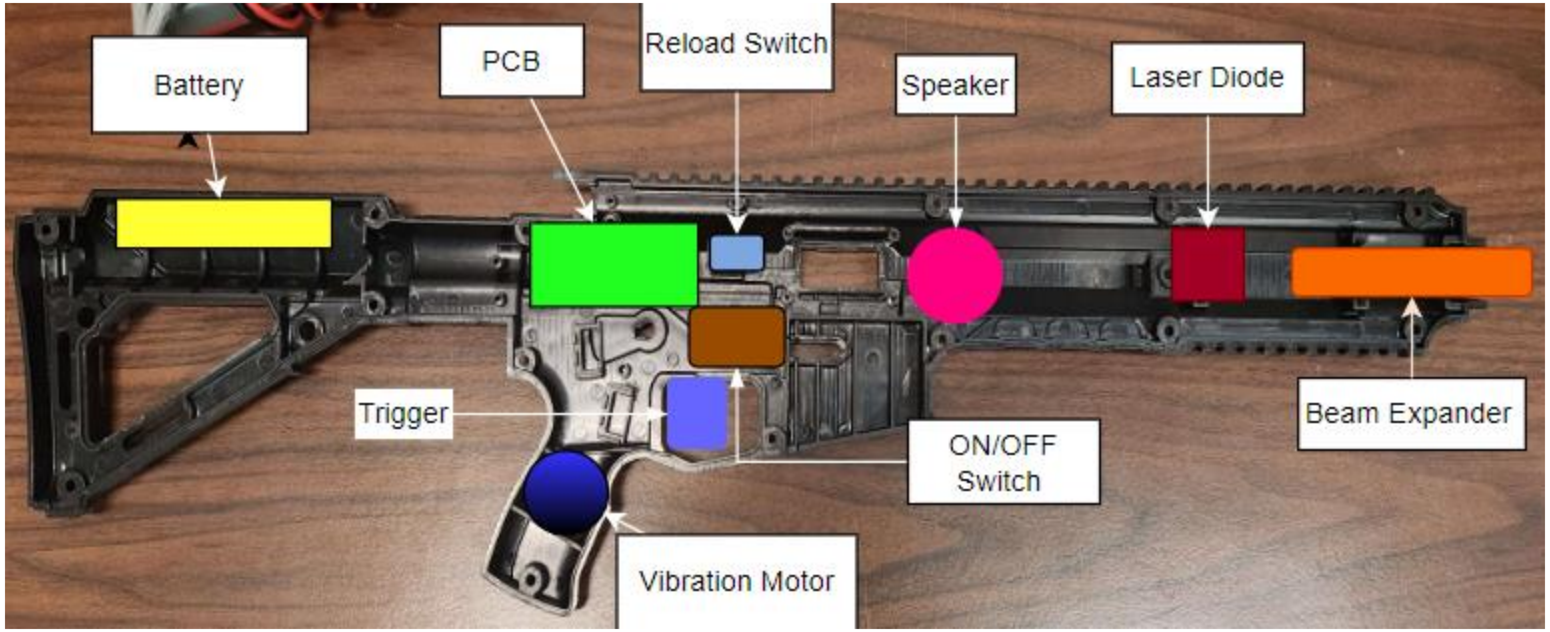


Target Board



Laser Board

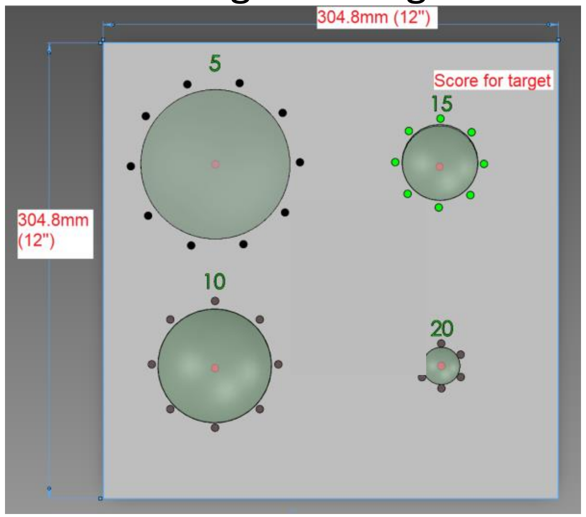
Rifle Enclosure



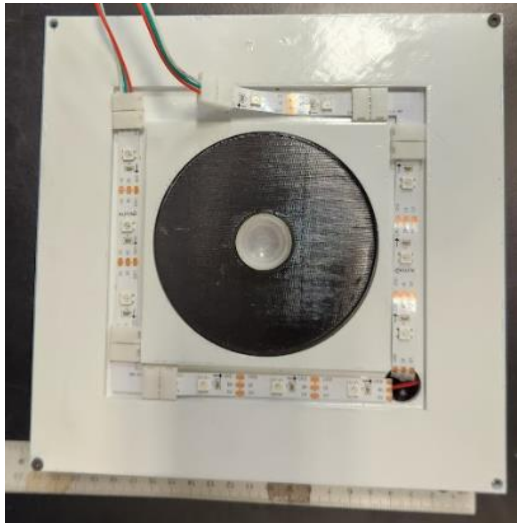
Target Board Enclosure

- Entirely 3D printed with two separate front and back panels
  - Lenses are printed separately
- Board spray painted using glossy white paint
  - Increases light reflectivity for use with IR flashlight
- Originally had 4 receivers for 4 separate targets on the board
  - Switched to a single target with variable target area

Original Design



New Design

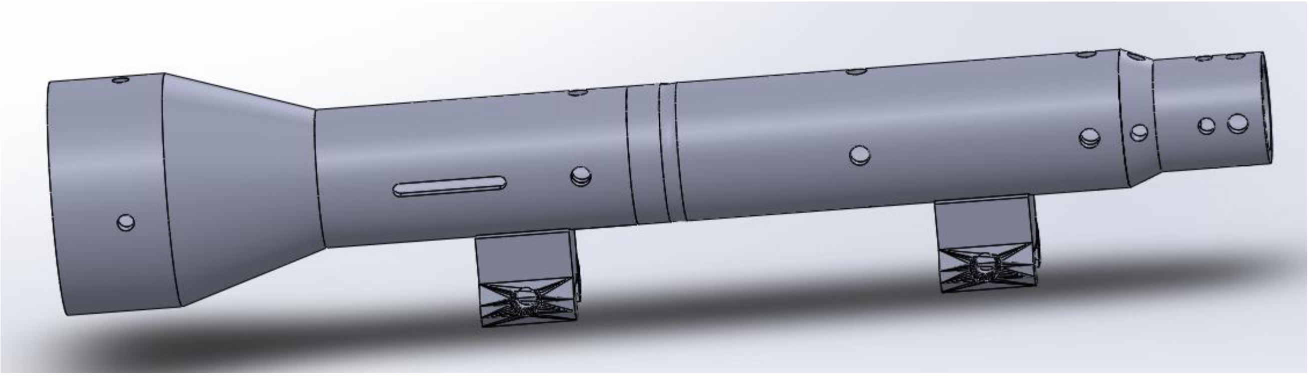


Target Areas

Rifle Scope Enclosure

- Entirely 3D printed
  - Screws used to hold in lenses
- 3 separate parts that are connected together using screws
- Two moving lens tubes
  - Side focus lens moves axially to adjust for parallax error
  - Erector assembly moves horizontally and vertically for reticle calibration

Scope Design



Mounted on Rifle

Night Vision System Implementation

- Camera Box mounts onto scope
  - Contains camera, lens system, and 12V battery for power
- LCD Display and IR Flashlight
  - Mount onto side rails

Bill of Materials

Item Type	Expected ($)	Actual ($)	Quantity
Rifle Frame	100	230	1
IR Laser Diodes	75	150	10
Visible Laser Diode (no longer being used)	20	12	30
Lenses	300	100	30
CMOS Camera	50	40	1
LEDs	40	30	100
3D Printer Clear PETG 3D Printer Black PLA	100	40 17	2 1
IR Receivers	40	18	25
Batteries	60	17	2
Speaker	10	9	2
PCB	40	MISC	5
MCU MCU Dev Board	16 16	8 16	2 2
Vibration Motors	10	13	15
Misc. Components	40	MISC	MISC
Total	**$917**	**$700+MISC**	

Future Improvements

- Add gameplay to our project.
- Custom Vibration patterns for the Laser Rifle
- Change the color of the LED strips of the Target Board using app
- More accessories for the Laser Rifle.
    - Other types of sights (reflex, holographic)

Laser Target-Shooting

Group 6

Cameron Vo – Optical Engineering

Eltholad Orelien – Electrical Engineering

David Johnson – Electrical Engineering

Quang Pham – Computer Engineering

CONCLUSION