Shooting Gallery Simulator

Senior Design
Group 8

Our Main Goal

Our team wanted to create equipment for hunting training that would be safer to use than the current standard, as well as be more affordable and have a more compact design. The equipment includes a hunting rifle and a target board. The main way of achieving this goal was by using a laser diode as our source of ammunition instead of physical bullets, and having a target board that used photodiode detection.

Our Team

Mariela Montanez

Optics and Photonics Engineer

Ivanna Socarras

Computer Engineer

Zachary Romanoff

Electrical Engineer

Motivation and Background

Ethical and Safety Considerations

- Hunting requires a high level of awareness, precision, and ethical responsibility.
- Hunters must quickly identify targets and ensure safe, responsible shots.
- Accurate and precise shot placement is essential for ethical hunting practices.

Limitations of Traditional Training Methods

- Precise shot placement is essential for ethical hunting practices which carries inherent risks
- Opportunities for beginners to practice safely may be limited.

Overall Impact

- Supports responsible hunting practices.
- Prepares participants for real-world field situations.
- Builds confidence through practical, risk-free skill development.

Purpose Behind the Project

- Provides a controlled and safe environment for new hunters.
- Helps users develop essential skills without live ammunition.
- Allows practice of aiming accuracy and reaction timing safely.

Goals and Objectives

Safety and Feedback

- Ensure the user has a safe training experience.
- Provide useful feedback on shot accuracy and reaction time.

Realistic Training Experience

- Implement additional detachable features to enhance realism, including a range finder system and a rifle scope.
- Allow modular attachments to accommodate user preferences and needs.

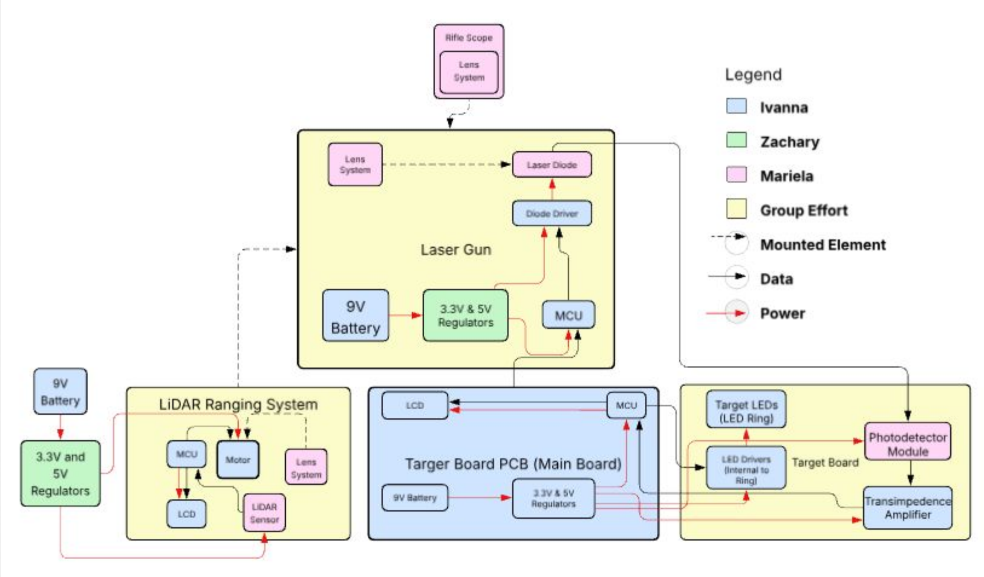
Budgeting

Achieve all project goals while staying within a reasonable budget.

Hardware Design

Overall Goals:

- Modular Design
- Support Different Required Power Systems
- Incorporate optical elements
- Incorporate clear feedback and user input



Engineering Specifications

Requirement	Specification
Trigger Response Time	≤ 1s. The trigger will have a maximum allowable time delay between the physical trigger crossing its predefined activation threshold and the laser diode beginning to emit light.
Laser Hit Detection Time	≤ 1s. The target will have a maximum allowable time delay from the moment the laser pulse strikes a target's photodiode sensor to the MCU registering the event.
Hit Detection and Reporting Accuracy	≥ 95%. The system is expected to correctly identify a valid laser pulse from the rifle and provide visual feedback to the user while also rejecting false inputs. Accuracy is a measure of correctly identified hits (true positives) and correctly ignored non-hits (true negatives).
Rifle Scope and Rifle Range	Scope focus and Rifle sensing distance > 20 meters. This is the maximum distance we want our system to operate at, so both systems should perform as intended at this distance..
Rifle Scope Magnification (Angular)	Scope magnification 6x. The scope should be able to magnify the chosen target in order to fire a shot accurately.
Laser Diode Beam Magnification	8x. The beam should be large enough to where the photodiode system can easily detect the incoming optical signal, but also not be too large to where it is not realistic to a true hunting scenario.

LiDAR Modules Selection

Criteria	DFR1183	Lidar Light V3
Angular Resolution	Decreases sensing accuracy	Not an issue since it is not a scanning Lidar module
Cost	$70 USD, better for our desired total budget	$131 USD, slightly more expensive but still fits the budget
Maximum Sensing Distance	12 meters, well under our desired minimum distance	40 meters, exceeds our desired minimum distance

Basic requirements:

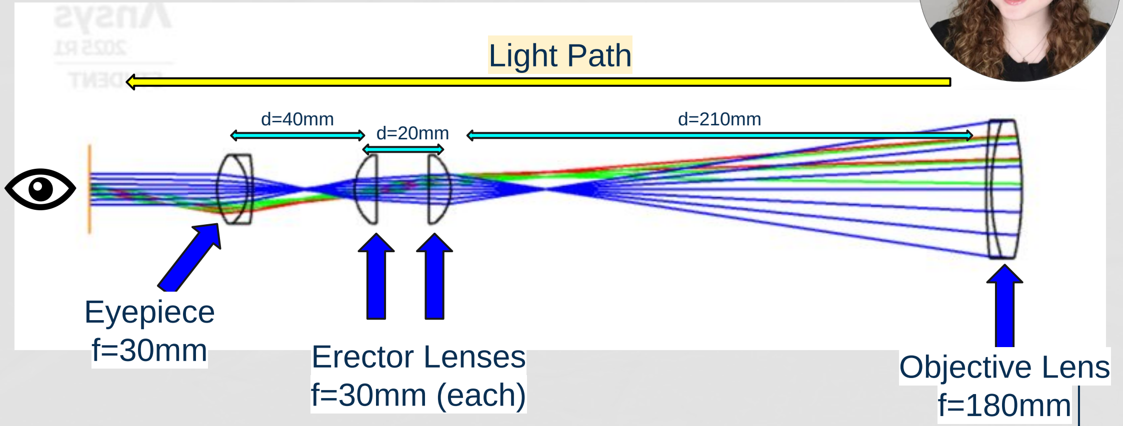
- Sensing accuracy
  - Requires good angular resolution
- Minimum sensing distance of 20 meters
  - Dependent on SNR, laser power/energy, and more
- Fit into our budget requirements
  - Preferably less than $100, but can be flexible

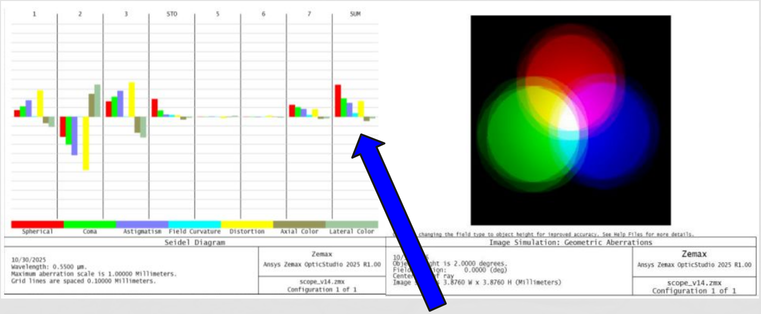
Rifle Scope Lenses Selection

Objective Lens		Erector Lenses		Eyepiece Lens	
Component	**Specification**	**Component**	**Specification**	**Component**	**Specification**
Achromatic Doublet Lens (Thorlabs AC508-180-A)	f=180mm, d=2”	**Plano Convex Lens (Thorlabs LA1805-A, x2)**	f=30mm, d=1”	**Plano Convex Lens (Thorlabs LA1805-A, x2)**	f=30mm, d=1”
Plano-Convex AR Coated Lens (LA1979-A)	f=200mm, d=2”	**Achromatic Doublet AR Coated Lens (AC254-030-AB,x2)**	f=30mm, d=1”	**Achromatic Doublet AR Coated Lens (AC254-030-AB,x2)**	f=30mm, d=1”
Plano-Convex Uncoated Lens (LA1979)	f=200, d=2”				

Rifle Scope Design

- Two achromatic doublets used to reduce chromatic aberrations
- Cost minimized by using plano-convex lenses for erector system
- Parallax and focusing issued may be corrected by having an adjustable objective lens

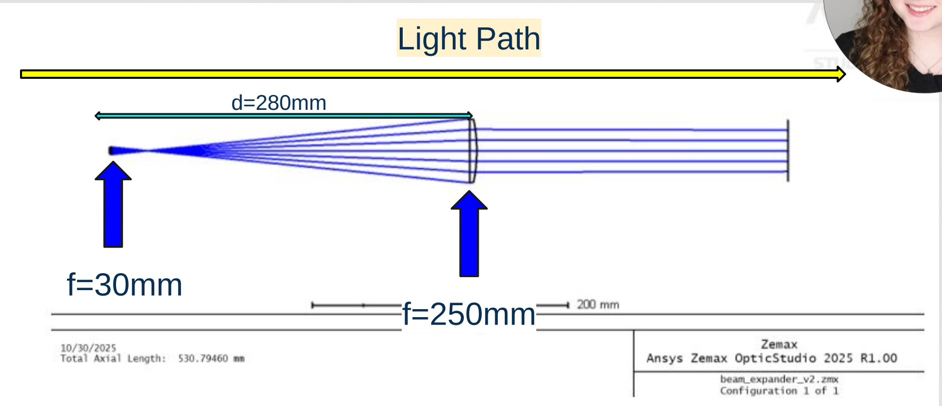


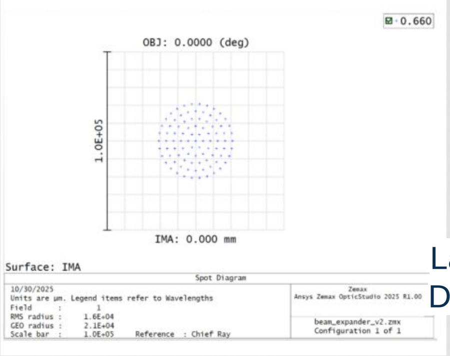


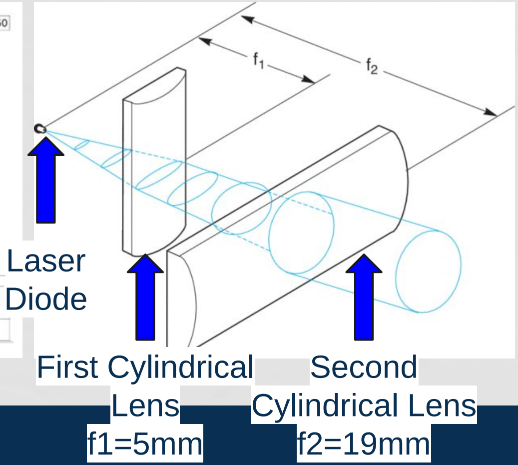
Final aberrations present within system

Beam Expander System Design

- Magnification of x8
- Keplerian beam expander for better beam quality and collimation
- Two perpendicular cylindrical lenses will be present before the beam expander
- Total system length is approximately 12 inches
- Laser diode for this system is a 7mW diode with λ=658nm (red light)

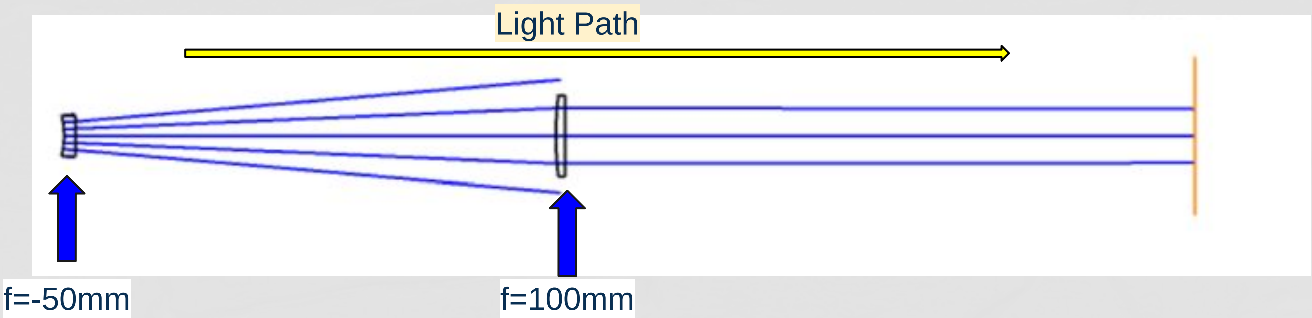






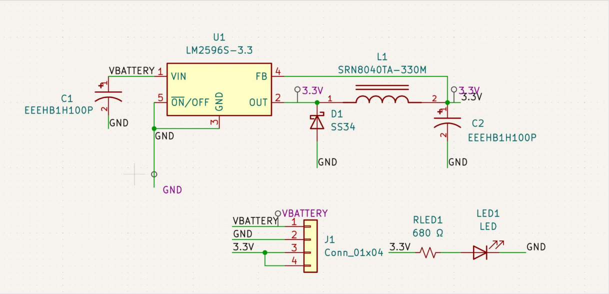
Lidar Lens System Design

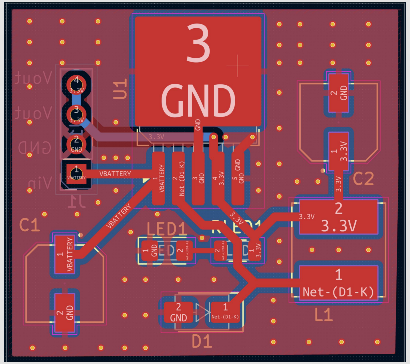
- Galilean lens system
- Used to slightly increase range and beam size
- Second lens will move for automatic focus



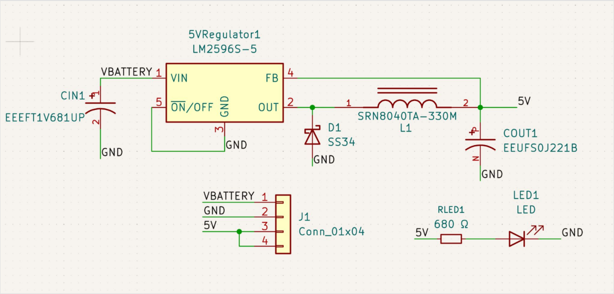
Board Design: Power Distribution (Regulators)

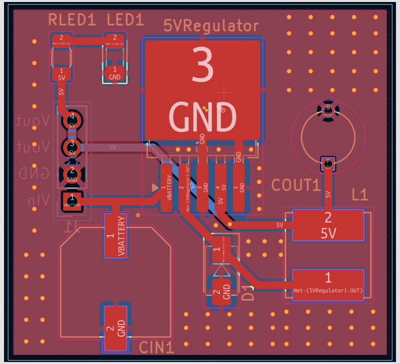
3.3 V





5 V





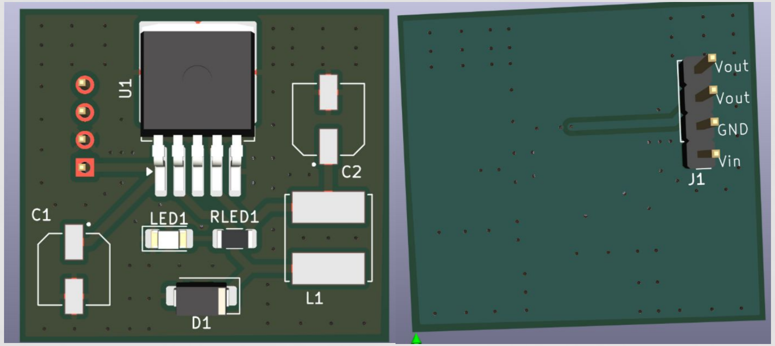
- Implemented into laser rifle and lidar autofocusing system
- Similar Design
- Connection to other boards
- Trace Sizing/Specific Component Placement
- Component Selection (Current minimums)

Designed by our former group member Zachary Romanoff

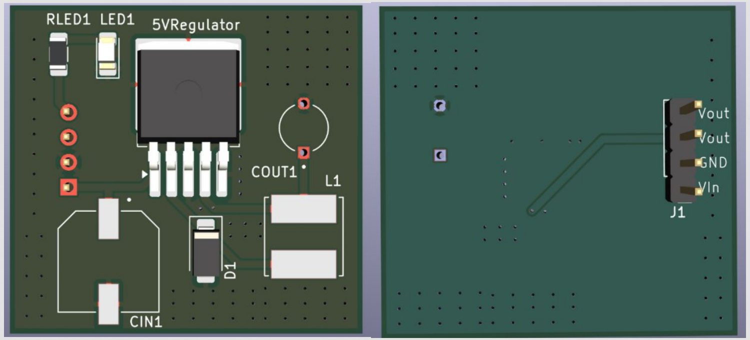
Board Design: Power Distribution (Regulators)

Connection on bottom of board

3.3 V

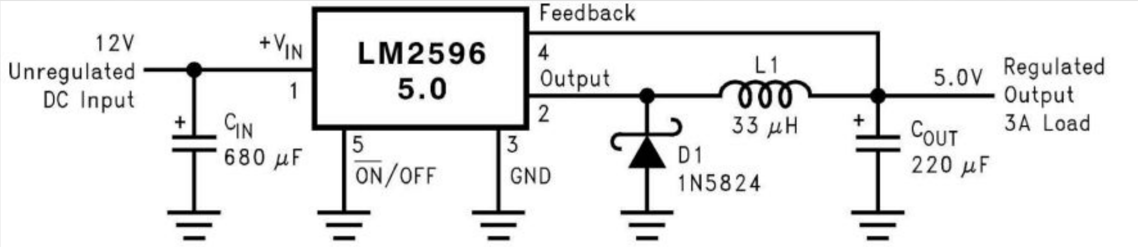


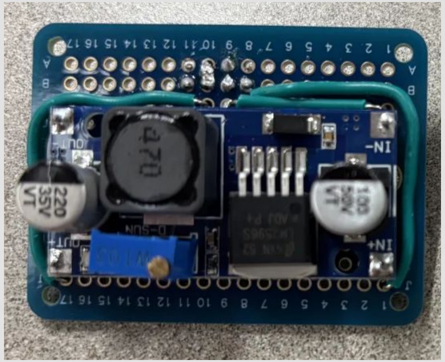
5 V



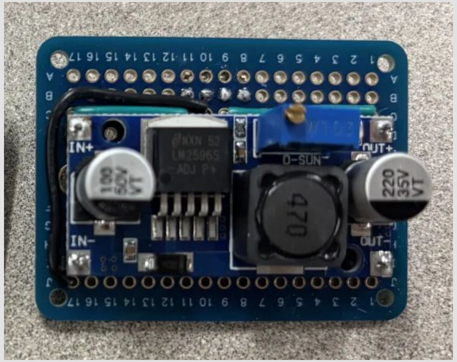
Designed by our former group member Zachary Romanoff

Board Design: Power Distribution (Regulators)





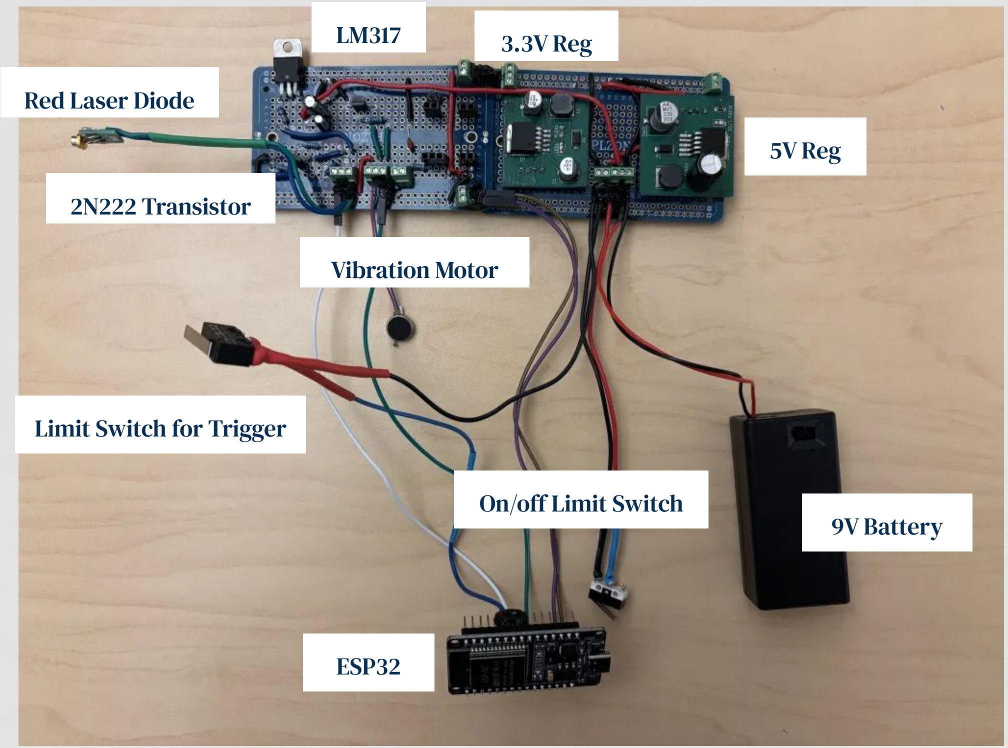
3.3V



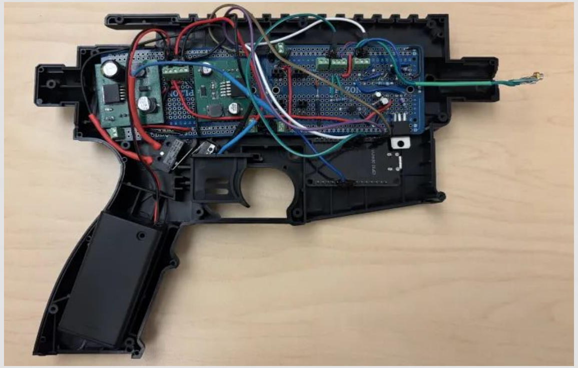
5.0V

- LM2596 DC to DC step-down (buck) switching regulators
- Capable of driving 3A load
- Output voltages of 3.3V and 5V
- Soldered onto protoboard

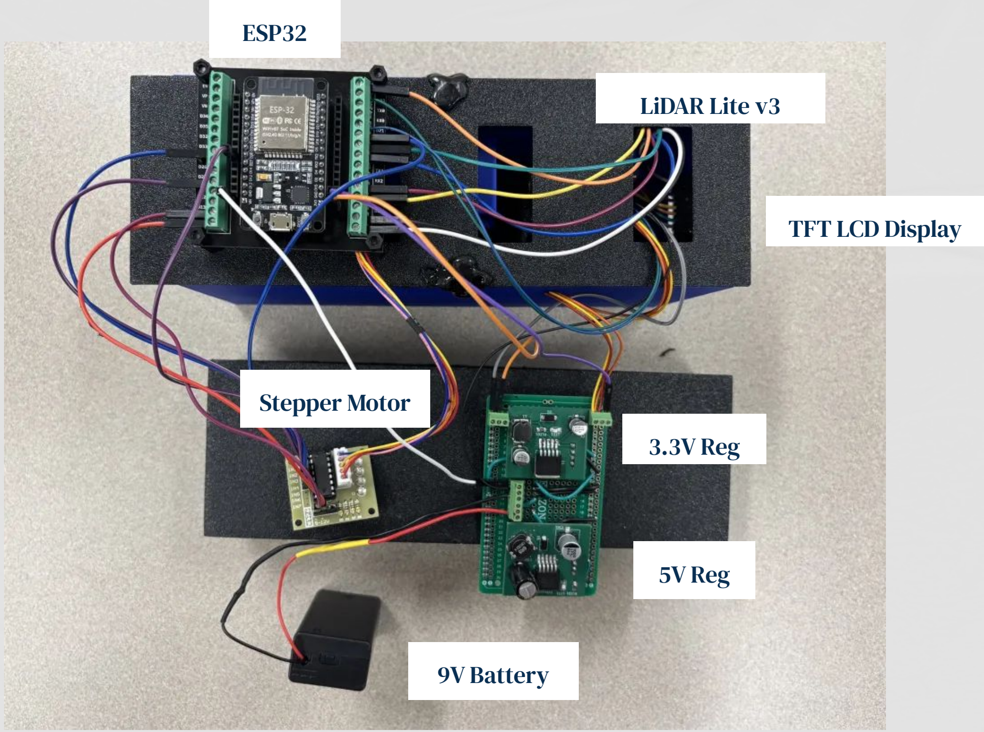
Board Design: Laser Rifle and Laser Driver



- LM317 used to drive laser diode
- 2N222 transistor to switch diode on and off
- Red laser diode

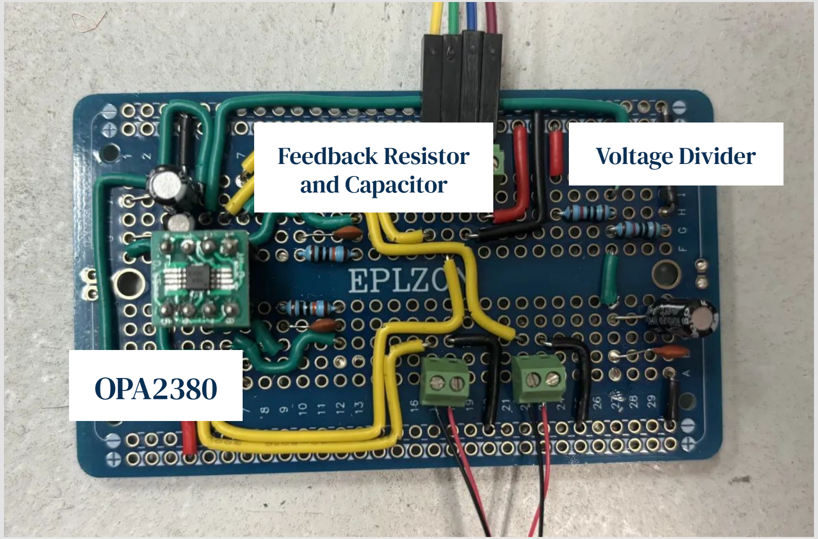


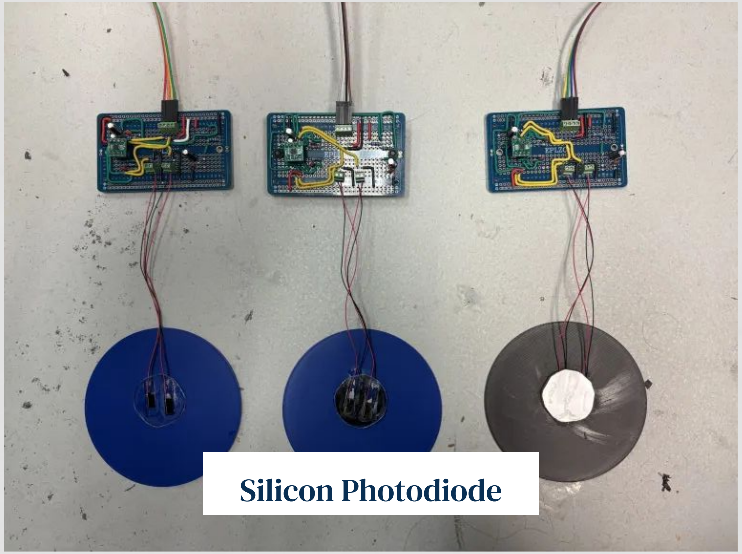
Board Design: LiDAR Autofocusing System



- ULN2003 driver board used to move 28BYJ-48 stepper motor

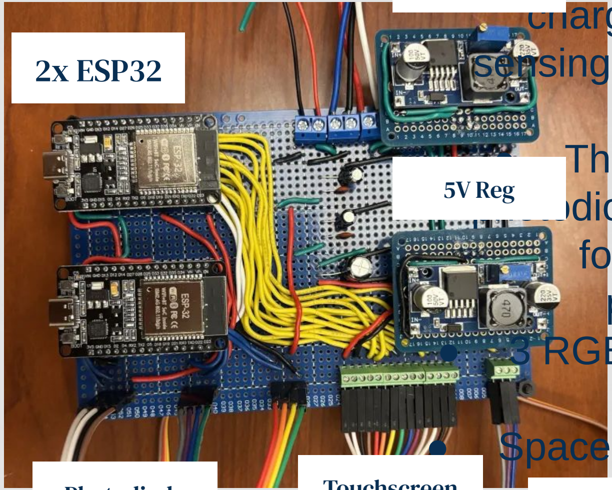
PCB Design: Photodiode Driver



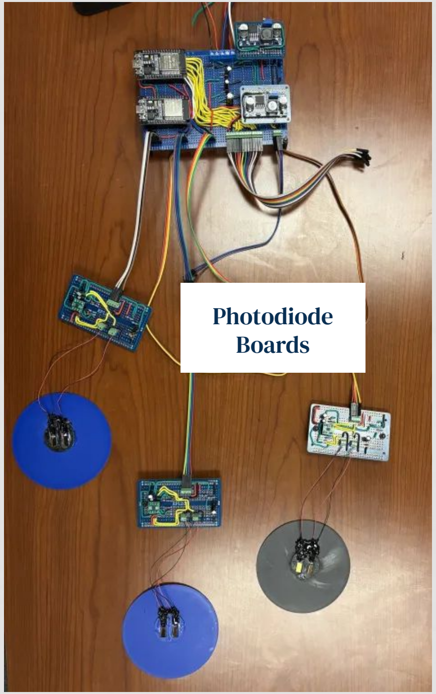


- OPA2380 Transimpedance amplifier for two input values
- Two SLSD-71N300 Silicon Photodiode for each target
- Voltage divider halves the ESP32 input voltage from 3.3V to 1.65V

PCB Design: Main Board in Target Board



- ESP32 MCUs, one in charge of photodiode sensing the other in charge of UX/UI
- Three spaces for odiode boards allowing for a total of six photodiodes
- 3 RGB LED rings daisy chained
- Space for a touchscreen D display

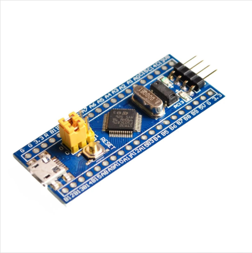


Microcontroller Unit Selection Requirements

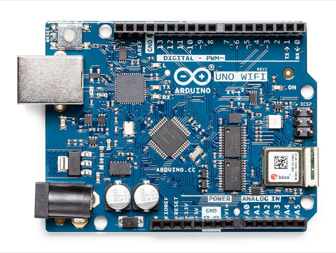
- Real-time control capabilities for deterministic timing
- Sufficient clock speed
- Low power consumption
- Sufficient GPIO count for all peripherals
- Support for high-level programming languages
- Low costs and wide availability
- Reusable across all subsystems

ESP32

Raspberry Pi



STM32F103



Arduino Uno WiFi

Microcontroller Unit Selection

Feature	ESP32	Raspberry Pi	STM32F103	Arduino Uno
GPIO Count	36	40	37	14
Development	C/C++	Linux	C/C++	C/C++
SRAM (KB)	512	(SDRAM) 16 GB	20	6
Clock Speed (MHz)	240	1000	72	16
Price	$10	$20	$12	$55

Laser Rifle: Hardware to Software Integration

Tasks:

LiDAR Management:

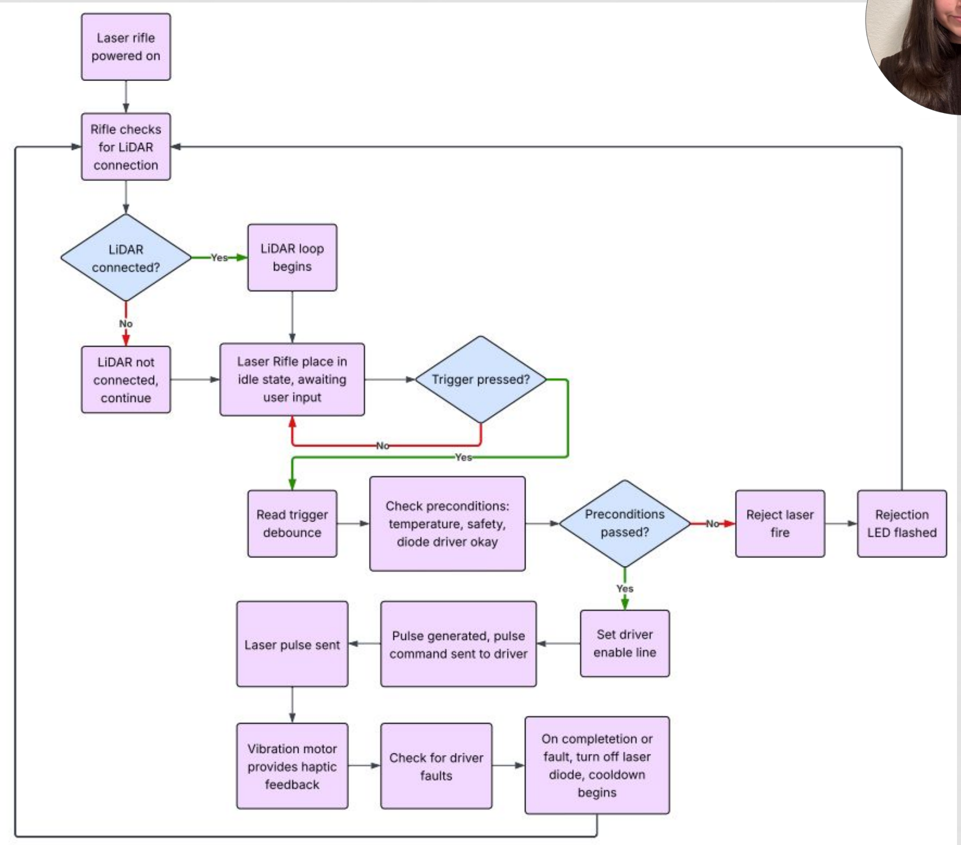
- Detects LiDAR presence
- Initializes LiDAR when connected
- De-initializes when disconnected

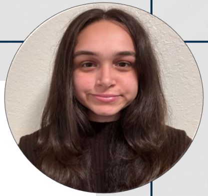
User Input:

- Trigger input handling
- Generates fire requests

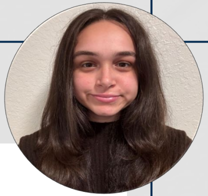
Feedback Control:

- Enables laser driver
- Controls vibration motor





LiDAR: Hardware to Software Integration



Tasks:

LiDAR Measurement:

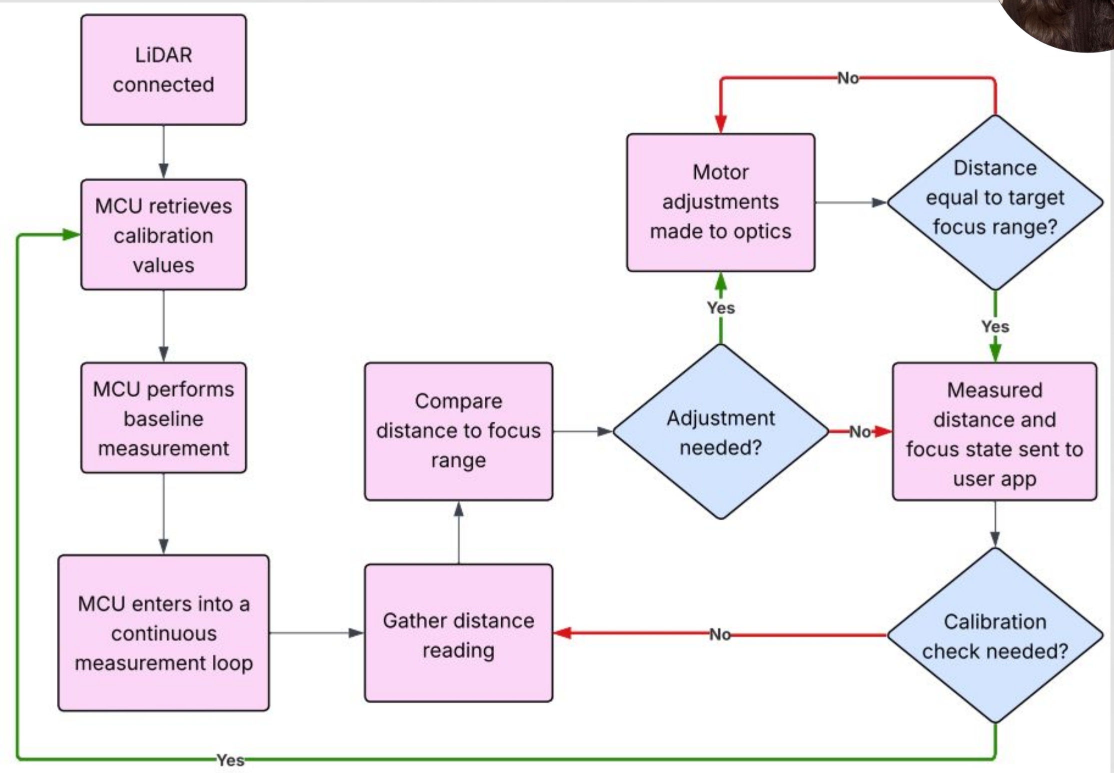
- Runs continuous distance measurement loop
- Provides validated distance data

Autofocus Control:

- Compares measured distance to focus range
- Determines if optical adjustment is needed
- Commands motor adjustments to lens system

System Interface:

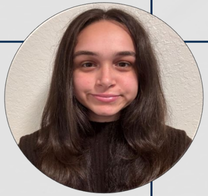
- Sends data to LCD display



LiDAR: Lens Mapping

- The signal strength of the LiDAR lite v3 was measured at several distances
- Signal strength was approximated by evaluating the consistency of repeated measurements
  - Stronger signal = stable repeatable readings
  - Weaker signal = introduction of noise and variation
- Lens position was adjusted to find the optimal signal strength
- Signal strength increased to 140 in each

Distance (cm)	Strength without Lenses	Lens Distance (mm)	Strength with Lenses
100	126	690	140
300	126	670	140
400	112	650	140
500	112	600	140
600	112	550	140
800	112	550	140
1000	98	500	140
1500	98	500	140
2000	98	500	140



Target Board Hardware to Software Integration

Tasks:

Hit Detection and Sensing Loop:

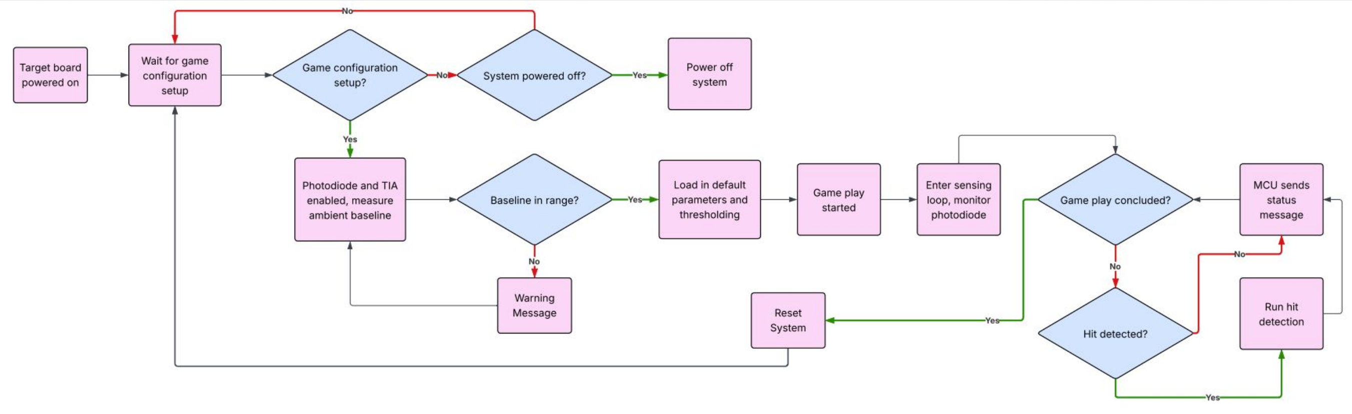
- Runs continuous sensing loop during sessions
- Monitors photodiode readings for events
- Prevents false triggers

Sensor Baseline and Thresholding:

- Enables photodiode and TIA sensing
- Measures ambient baseline
- Loads default parameters and hit thresholds

User Interface:

- LCD display reports game state, hit events and warnings
- LCD display is touchscreen
- LED lights for visual feedback



Touch Display Interface

Home Screen:
- User chooses between play or performance

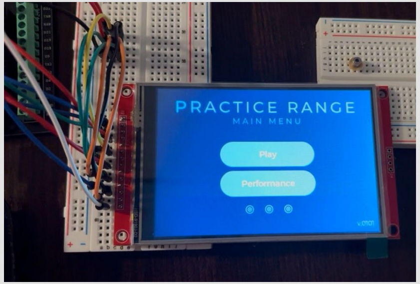
Mode Selection Page:
- Provides system with game logic needed
- Reaction Based session or Timed Freestyle session

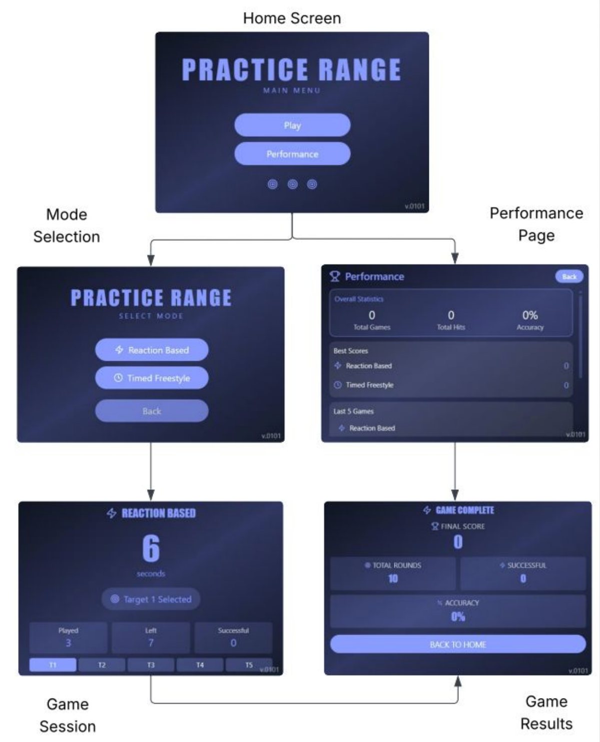
Reaction Based:
- Allows user to choose between 10 or 15 rounds
- Screen shows the chosen target and time left for current round

Freestyle Session:
- Allows user to choose between 60 or 120 seconds
- Screen shows a count down and number of targets hit

Game Results:
- Reaction Based: displays successful rounds and accuracy
- Freestyle: displays number of targets hit

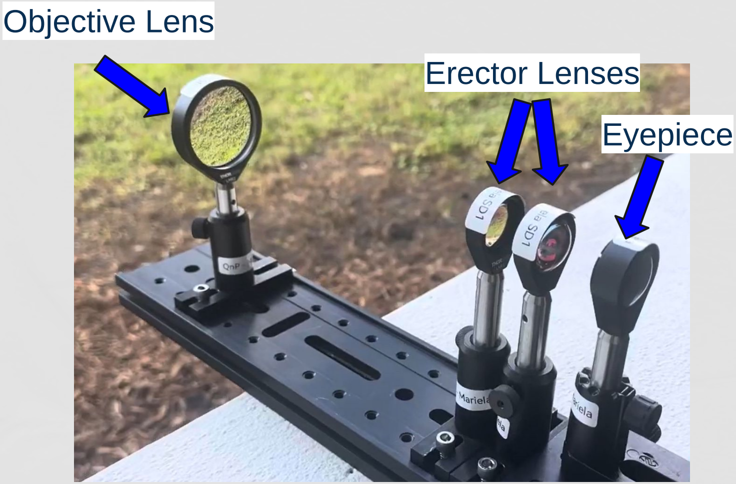
Performance Screen:
- Overall stats: total games, total hits, accuracy
- Choose to look at previous 5 sessions

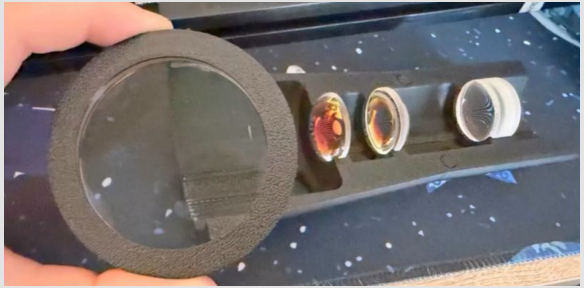




Prototype and Testing: Rifle Scope

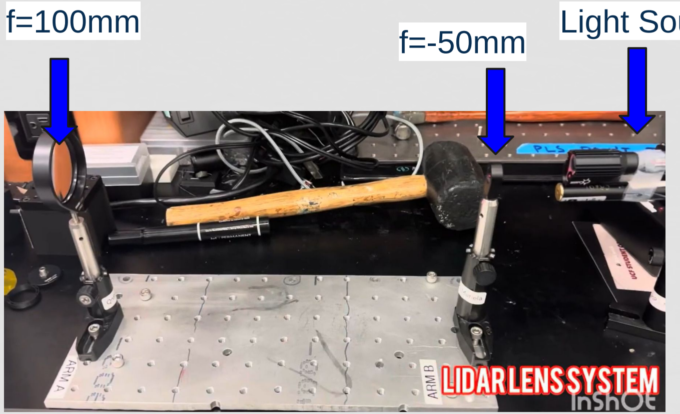
- Clear focus throughout system
- Few chromatic aberrations
- Angular magnification of 6x achieved

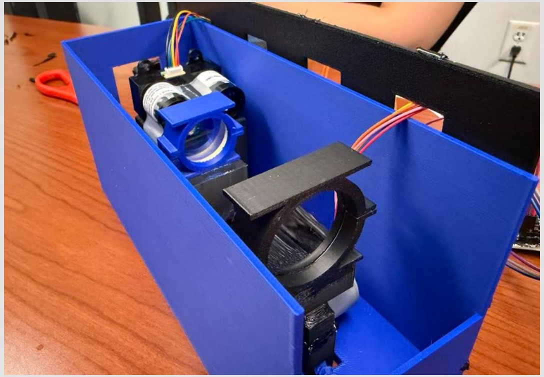




Prototype and Testing: LiDAR Lens System

- Tested using collimated light source
- Shows clear beam all throughout
- System keeps beam collimated at long distances





Prototype and Testing: Beam Expander Lens System

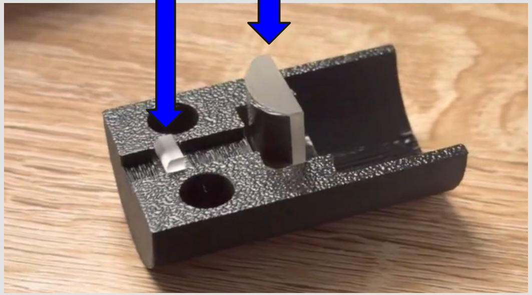
- Cylindrical lenses reshape the beam
- Plano-convex lenses create Keplarian beam expander
- Circular spot is created once the beam passes through system

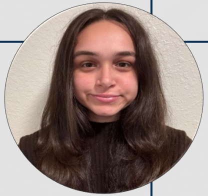
f=250mm

f=30mm

f=19.7mm

f=5.79mm





Prototype and Testing: Target Photodiode Sensors

- Raw testing of each photodiode showing a decrease of voltage due to the voltage divider added to each photodiode board
- Sensitivity of current photodiode causes a voltage around 1.8-2.2V

```
I (24675) TargetSense: ********************************************************************************
I (27685) TargetSense: P1: raw=2359  voltage=1.901 V  current=2.510 uA  delta=10       HIT: NO
I (27685) TargetSense: P2: raw=2520  voltage=2.031 V  current=3.808 uA  delta=-2       HIT: NO
I (27695) TargetSense: P3: raw=2465  voltage=1.986 V  current=3.364 uA  delta=-32       HIT: NO
I (27695) TargetSense: P4: raw=2449  voltage=1.974 V  current=3.236 uA  delta=-10       HIT: NO
I (27705) TargetSense: P5: raw=1455  voltage=1.173 V  current=-4.775 uA  delta=541       HIT: NO
I (27715) TargetSense: P6: raw=2556  voltage=2.060 V  current=4.098 uA  delta=-33       HIT: NO
I (27725) TargetSense: ********************************************************************************
I (30735) TargetSense: P1: raw=2417  voltage=1.948 V  current=2.978 uA  delta=21       HIT: NO
I (30735) TargetSense: P2: raw=2536  voltage=2.044 V  current=3.937 uA  delta=-5       HIT: NO
I (30745) TargetSense: P3: raw=2486  voltage=2.003 V  current=3.534 uA  delta=-12       HIT: NO
I (30745) TargetSense: P4: raw=2445  voltage=1.970 V  current=3.203 uA  delta=-16       HIT: NO
I (30755) TargetSense: P5: raw=1472  voltage=1.186 V  current=-4.638 uA  delta=558       HIT: NO
I (30765) TargetSense: P6: raw=2629  voltage=2.119 V  current=4.686 uA  delta=19       HIT: NO
I (30775) TargetSense: ********************************************************************************
I (33785) TargetSense: P1: raw=2391  voltage=1.927 V  current=2.768 uA  delta=-10       HIT: NO
I (33785) TargetSense: P2: raw=2530  voltage=2.039 V  current=3.888 uA  delta=-10       HIT: NO
I (33795) TargetSense: P3: raw=2489  voltage=2.006 V  current=3.558 uA  delta=-4       HIT: NO
I (33795) TargetSense: P4: raw=2433  voltage=1.961 V  current=3.107 uA  delta=-21       HIT: NO
I (33805) TargetSense: P5: raw=1444  voltage=1.164 V  current=-4.863 uA  delta=530       HIT: NO
I (33815) TargetSense: P6: raw=2553  voltage=2.057 V  current=4.074 uA  delta=-27       HIT: NO
I (33825) TargetSense: ********************************************************************************
I (36835) TargetSense: P1: raw=2399  voltage=1.933 V  current=2.833 uA  delta=-2       HIT: NO
I (36835) TargetSense: P2: raw=2547  voltage=2.053 V  current=4.025 uA  delta=9       HIT: NO
I (36845) TargetSense: P3: raw=2479  voltage=1.998 V  current=3.477 uA  delta=-11       HIT: NO
I (36845) TargetSense: P4: raw=2444  voltage=1.970 V  current=3.195 uA  delta=-10       HIT: NO
I (36855) TargetSense: P5: raw=1447  voltage=1.166 V  current=-4.839 uA  delta=533       HIT: NO
I (36865) TargetSense: P6: raw=2551  voltage=2.056 V  current=4.058 uA  delta=-25       HIT: NO
I (36875) TargetSense: ********************************************************************************
I (39885) TargetSense: P1: raw=2409  voltage=1.941 V  current=2.913 uA  delta=6       HIT: NO
I (39885) TargetSense: P2: raw=2549  voltage=2.054 V  current=4.041 uA  delta=16       HIT: NO
I (39895) TargetSense: P3: raw=2499  voltage=2.014 V  current=3.638 uA  delta=8       HIT: NO
I (39895) TargetSense: P4: raw=2439  voltage=1.965 V  current=3.155 uA  delta=-14       HIT: NO
I (39905) TargetSense: P5: raw=1449  voltage=1.168 V  current=-4.823 uA  delta=535       HIT: NO
I (39915) TargetSense: P6: raw=2558  voltage=2.061 V  current=4.114 uA  delta=-18       HIT: NO
I (39925) TargetSense: ********************************************************************************
```

Laser Diode Shot Detection

Distance from Target (cm)	Hits Detected Target 1	Hits Detected Target 2	Hits Detected Target 3	Average Detection Time	Accuracy
100	10	10	10	<1s	100%
300	10	10	10	<1s	100%
500	10	10	10	<1s	100%
600	10	10	10	<1s	100%
800	10	10	9	<1s	96.7%
900	9	10	10	<1s	96.7%
1000	9	9	9	<1s	90%
1300	10	10	9	<1s	96.7%
1800	9	9	9	<1s	90%
2000	8	9	8	<1s	83%

Prototype and Testing: LiDAR Subsytem Testing

Expected Distance (cm)	LiDAR Distance Reading (cm)	Lens Spacing Based on Map (mm)	Expected Stepper Motor Position	Stepper Motor Position
100	99	690	276	275
344	346	655	229	227
510	515	610	134	134
600	605	550	72	73
800	803	525	36	36
900	910	512	17	18
1000	1009	500	0	1
1300	1324	500	0	1
1800	1804	500	0	1
2000	2012	500	0	1

Budget

Item (Nomenclature)	Expected	Total
Electrical Components for Solder (Resistors, Capacitors, LEDs, etc)	$75	$75
PCBs - Production + Shipping	$200	$275
Test Equipment (Dev boards, breadboards, etc)	$50	$325
Extra Components for PCB (Stepper + Vibration Motor, Sound system components, LCDs, etc)	$50	$375
Power Components (Regulators, batteries)	$30	$405
Optical Equipment (Lenses, Lidar Sensor, etc)	$550	$955
3D Printing (Material + Operation)	$50	$1005

Work Distribution

Mariela Montanez
PSE

- Rifle Scope Design
- Laser Beam Lens System Design
- LiDAR Auto-Focus Lens Design
- Photodiode Lens System

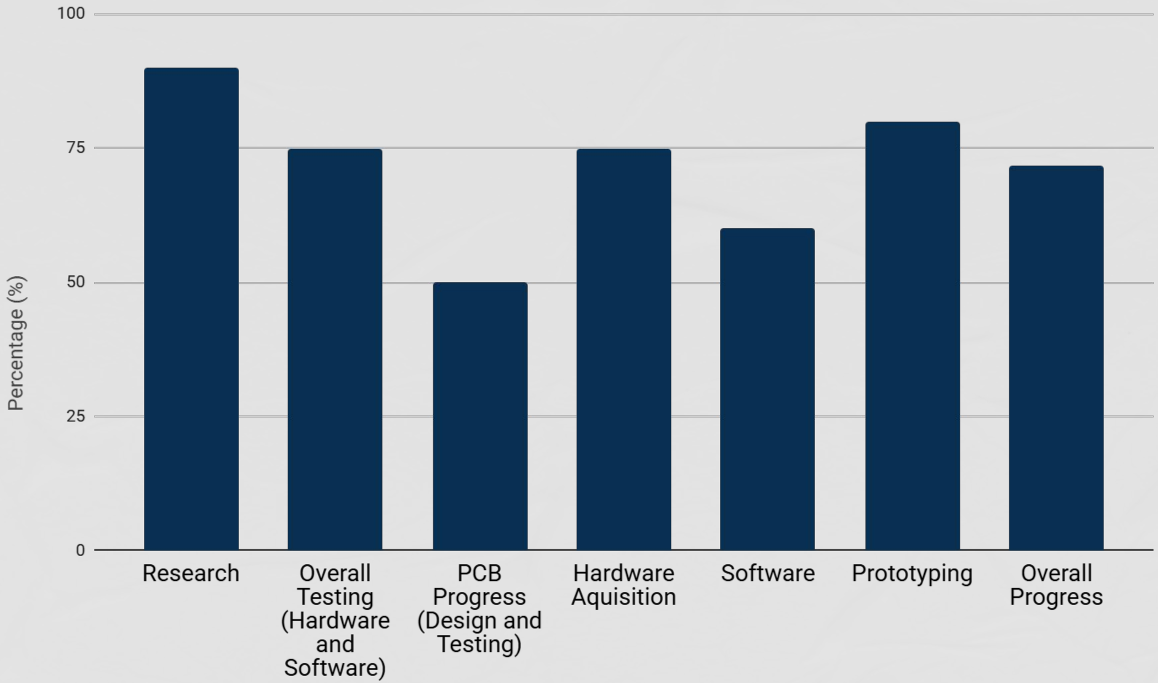
Ivanna Socarras
CPE

- Microcontroller Programming
- Sensor Data Acquisition and Processing
- Component Interfacing and Communication Protocols
- System Integration, Testing, and Debugging
- Algorithm Implementation
- PCB Design

Zachary Romanoff
ECE

- PCB Design
- Power System Design (Regulators, batteries, etc)
- Component Selection and Integration
- PCB Final Layouts (Tracing, soldering)

Initial Progress



Plan for Completion

Task	Responsibility
Design rifle scope and other lens systems in CAD	Mariela
Finish testing beam expander with cylindrical lenses	Mariela
Print and assemble designs for optical systems	Mariela
Create new PCBs and apply Development Boards	Ivanna
Test PCBs/Power Systems and Development Boards	Ivanna
Integrate all software onto hardware	Ivanna
System Testing	Ivanna
Optimize Code	Ivanna

Target Board