July 10, 2023

Dr. Michael Hegedus
School of Engineering
Simon Fraser University
8888 University Drive
British Columbia, V5A 1S6

Re: ENSC 405W Requirement Specifications

Dear Dr. Hegedus,

This design specification documentation for the Integrated Fire-Control Optic and Ballistic Solution was prepared by Company 15 in partial fulfillment of requirements for ENSC 405W: Project Design, Management, and Documentation (Capstone A).

This project was inspired out of a need for soldiers to effectively engage targets at unknown ranges with a greater degree of accuracy compared to existing rifle optic solutions. In addition, shooting from unconventional positions changes the trajectory of the projectile relative to the rifle optic and currently requires the soldier to mentally compute their point of aim at certain distances. Integrating a ballistic solution and fire control into the rifle optic itself reduces the amount of information a soldier must process to provide effective fire on target.

This document will address the following items:

- System Level Design,
- Product Design,
- Product Requirements,
- Product Specification,
- Ballistics Physics,
- Design Alternatives, and
- Test Plan.

Company 15 consists of 5 SFU Engineering students: Braden Choy, Bowie Gian, Mint Luc, Swapnil Patel, and Hong Shi.

Thank you for taking the time to review our design specification documentation for the Integrated Fire-Control Optic and Ballistic Solution. If there are any questions or concerns with our product, please contact the Chief Executive and Communications Officer Braden Choy at bchoy@sfu.ca.

Sincerely,

Braden Choy
Chief Executive and Communications Officer
Company 15

Integrated Fire-Control Optic and Ballistic Solution

Design Specification for ENSC 405W

Company 15
July 10, 2023

Name	Email Contact	Roles/Affiliations
Braden Choy	bchoy@sfu.ca	Chief Executive and Communications Officer
Bowie Gian	bgian@sfu.ca	Chief Technology Officer
Mint Luc	minh_luc@sfu.ca	Chief Marketing Officer
Swapnil Patel	svpatel@sfu.ca	Chief Financial Officer
Hong Shi	hxshi@sfu.ca	Chief Operations Officer

Abstract

This document outlines the design specifications of the Integrated Fire-Control Optic and Ballistic Solution (IFOBS) for use in improving a shooter's accuracy on target. The specifications will cover both the proof-of-concept and prototype phases of the device's development cycle and includes the mechanical, electronic, hardware, and software design choices and justifications. The particular decisions made for the design were based on the requirement specifications set out by Company 15 to meet the needs of the target market.

As militaries face an increasingly complex near-peer and insurgent threats, the common soldier's shooting position is rarely ideal and the distance to their target is never marked. IFOBS aims to automatically compensate for ballistic variables using a laser rangefinder and accelerometers integrated into the optic itself. In addition, a testbed will be developed to verify the accuracy of the ballistic solution from the optic. With a press of a button, a simple point of aim is generated to the shooter who can then return effective fire on target.

Table Of Contents

List of Figures

List of Tables

List of Equations

1 Introduction

Rifle scopes are an essential part of military training and significantly contribute to improved accuracy and marksmanship. Precision and effectiveness are critical in the context of army training. The U.S. Army is currently evaluating an innovative rifle scope that incorporates a unique safety feature, ensuring that the user cannot fire the rifle unless the shot is guaranteed [1]. This design specification document describes the decisions made in the creation of a sophisticated rifle sight with this safety feature that is especially suited for military usage. The goal of the scope is to give soldiers more accurate target acquisition and dependable performance in a variety of environmental settings. Through detailed explanations and illustrations, this document will delve into the design choices, features, and considerations that have been made to ensure the rifle scope meets the demands of army training.

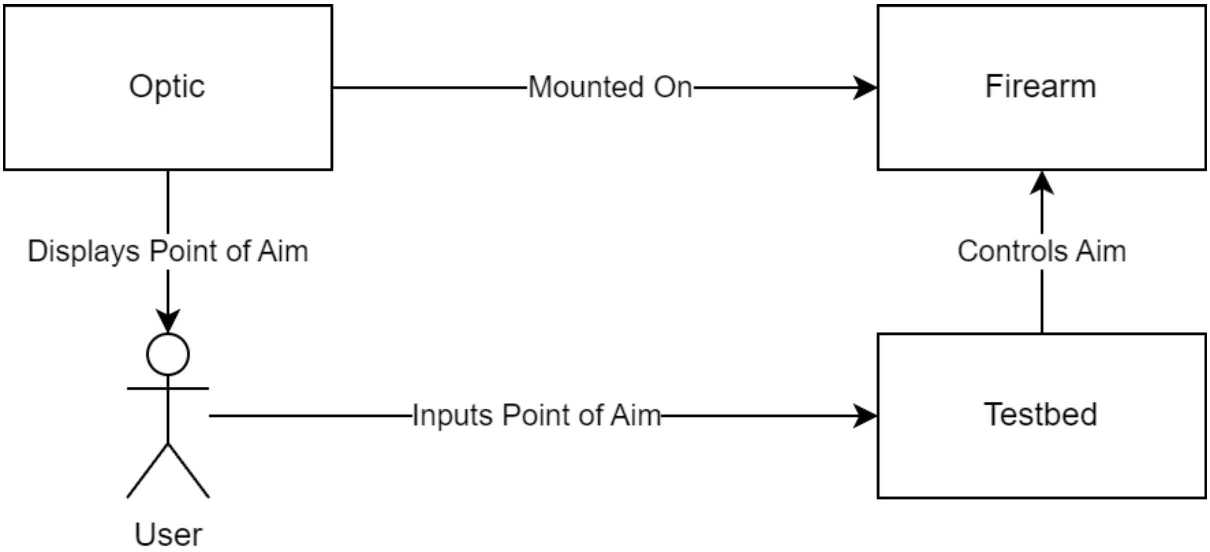

Figure 1 - High level block diagram of the optic and testbed

1.1 Scope

In this document, we will enumerate and justify the design choices made by Company 15 during the development of their advanced rifle scope. The design choices encompass various aspects such as system overview and IFOBS of the rifle optic and its testbed. We will provide detailed diagrams, schematics, and justifications for the design choices made. We will also explore alternative design options and test plan that were considered during the development process, ensuring that the final rifle scope delivers reliable and precise aiming

1.2 Challenges

To ensure the rifle scope's optimum usability and performance, many challenges had to be overcome throughout development. Some of the key challenges include:

- Precision and accuracy: Ensuring precise target acquisition and accuracy in different shooting scenarios
- Optics and clarity: Achieving high-quality optics with excellent light transmission, clarity, and minimal distortion, enabling clear visibility and target identification.
- Power efficiency: Maximizing power efficiency to prolong battery life and reduce the frequency of battery replacement or recharging.

1.3 Updates on Feedback

Following extensive feedback received from Dr. Mike Hegedus, several significant updates have been incorporated into the functionalities and design of the optic system, including:

1. Closed loop feedback control of the testbed system which will automatically adjust the rifle's position to compensate for cant and the range of the target. The adjusted point of aim must be identical to the calculated point of aim in the rifle optic.
2. Physically limiting the range of motion of the testbed system to prevent safety violations of negligently pointing a firearm at people or objects.
3. A comprehensive testing procedure that would minimize the effect of shooter bias or other human factors that would influence the accuracy of the results.

1.4 Requirement Types and Classification

The requirement categories are organized into four sections: General Rifle Optic, General Testbed, Hardware, and Software. Each requirement will be labeled in compliance with the following convention:

Req {Section}.{Subsection}.{Requirement Number}

Three further subclassifications are designated based on when each requirement is to be met in the product's development cycle.

Project Tag	Project Stage
A	Proof of Concept
B	Engineering Prototype
C	Production Version

Table 1.4.1 - Development Stage Encoding

2 System Overview

2.1 System Block Diagram

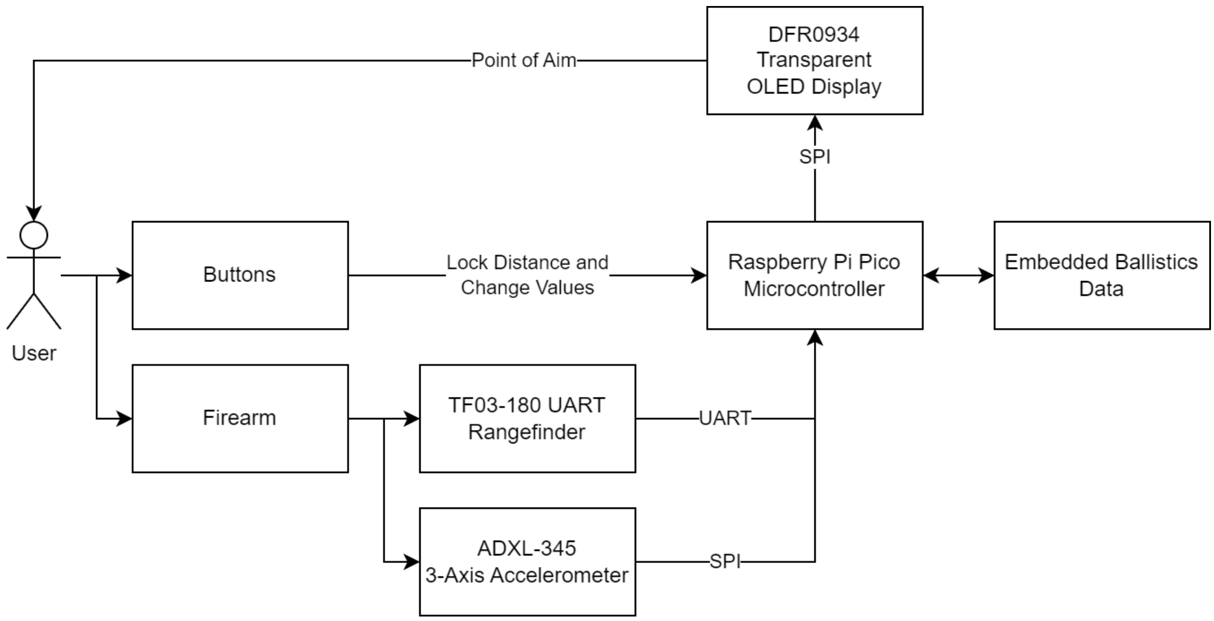

Figure 2.1.1: Fire Control Optic Block Diagram

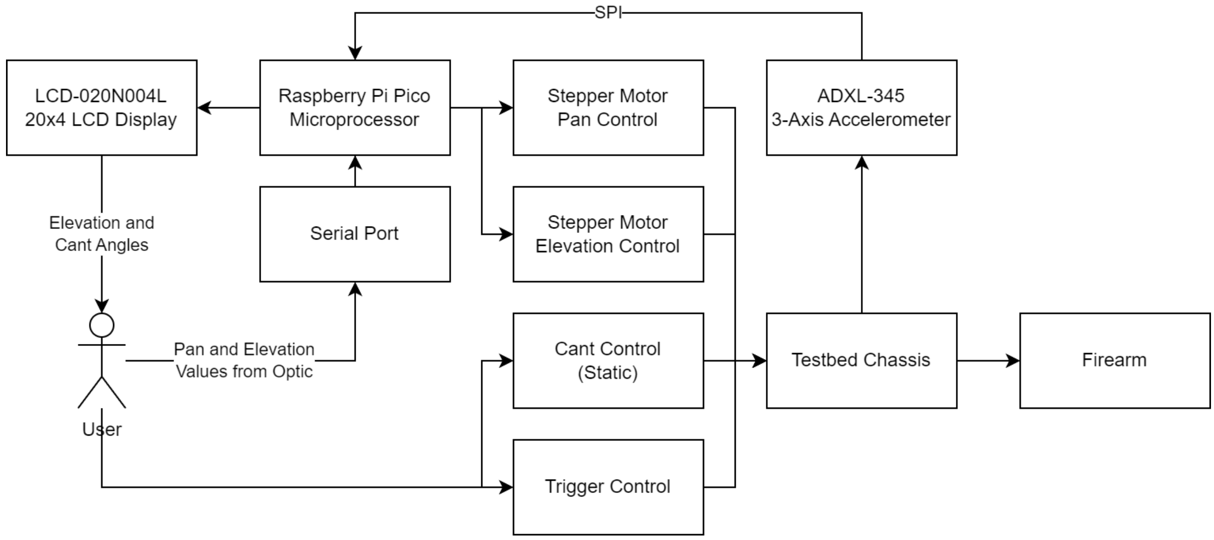

Figure 2.1.2: Testbed Block Diagram

2.2 Graphical Presentation

The two components of the Integrated Fire-Control Optic Ballistic Solution include the rifle optic and the testbed systems. Figure 2.2.1 illustrates the proposed design of the IFOBS system. Figures 2.2.2 to 2.2.5 illustrate the proposed design of the rifle optic system and the OLED display through a red dot sight. Figures 2.2.6 to 2.2.12 illustrate the proposed design of the testbed system including the standardized rail attachment systems.

Figure 2.2.1 - IFOBS Attached to a Rifle and Mounted in the Testbed

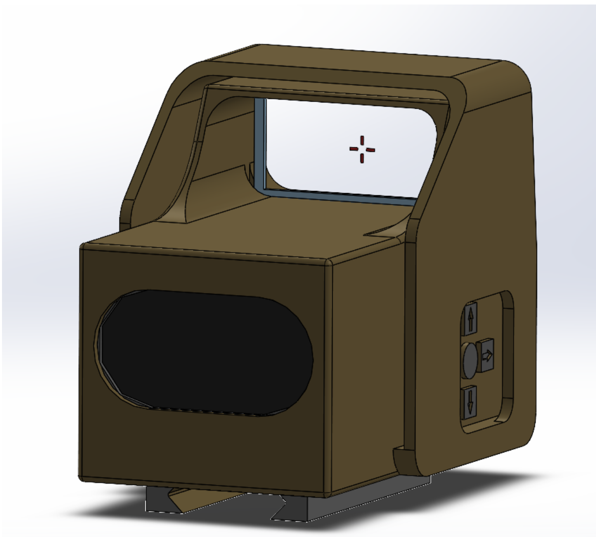

Figure 2.2.2 - Rifle Optic (Front)

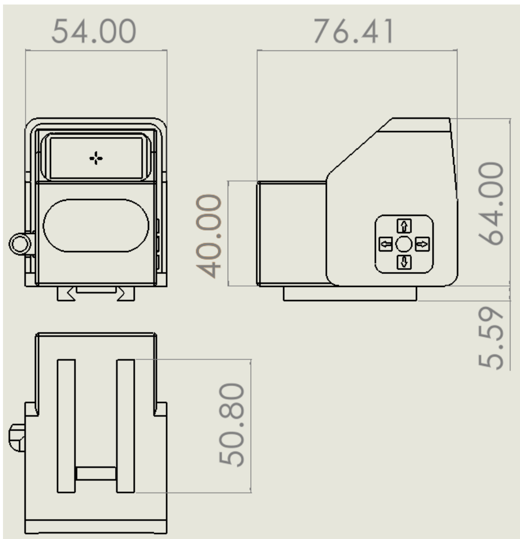

Figure 2.2.3 - Rifle Optic Dimensions

The rifle optic must be paired with an existing red dot sight or similar which is mounted to the rifle and is used to aim the laser rangefinder. Figure 2.2.4 illustrates the two optics mounted to a standard Picatinny rail and their position relative to each other. Figure 2.2.5 depicts the Rifle Optic in operation from the user's perspective.

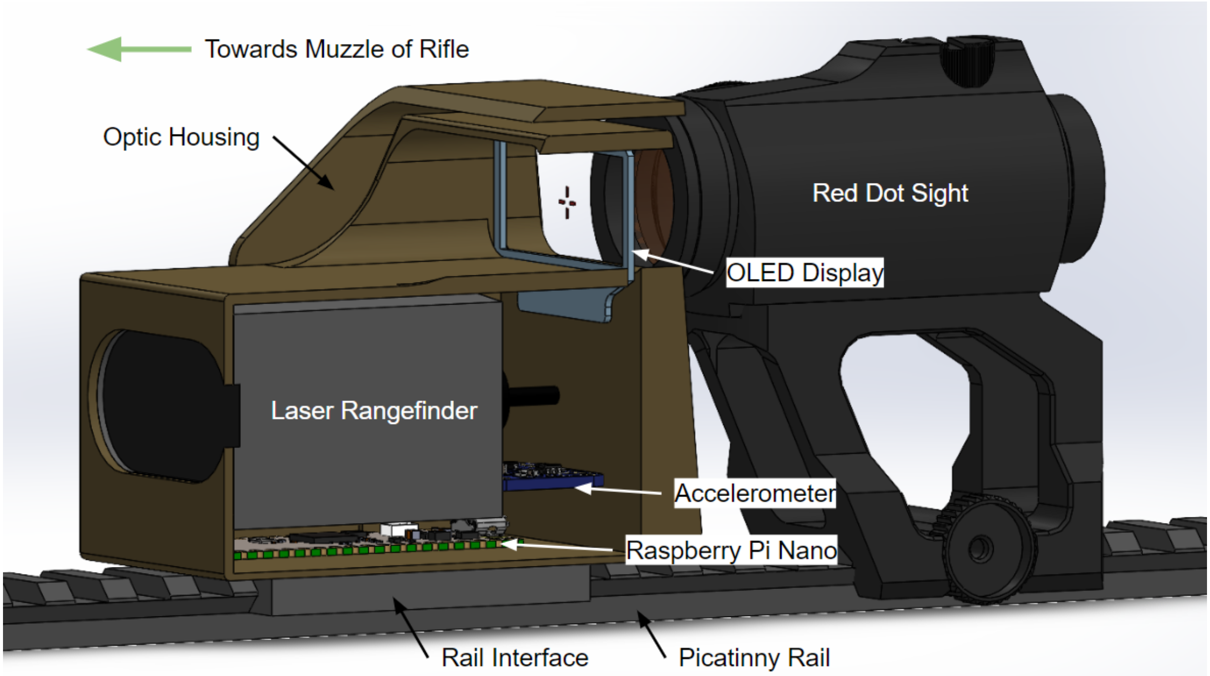

Figure 2.2.4 - Section View of the Rifle Optic Mounted in Front of a Red Dot Sight

Figure 2.2.5 - User's Perspective of the Rifle Optic in Operation

The testbed system mounts directly onto the attachment mount for the rifle which is a tripod ball head as illustrated in Figures 2.2.6 and 2.3.8. The testbed is oriented such that the LCD display faces the shooter. The buttstock of the rifle is secured into the clamp at the back of the testbed where the automatic positional adjustments are made.

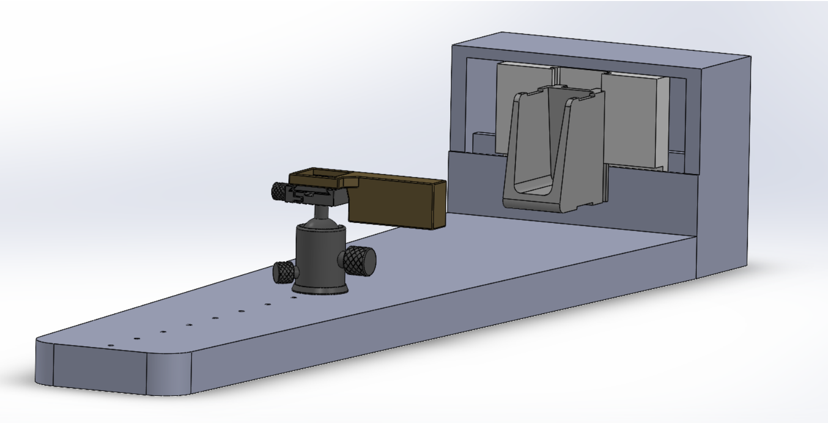

Figure 2.2.6 - Testbed System

Automatic positional control of the rifle is achieved with two stepper motors which are used to pan and elevate the rifle to the desired angles and are shown in Figure 2.2.7. The tripod ball head is secured to the rifle via Arca Swiss accessory rail attachment and sets the cant angle of the rifle.

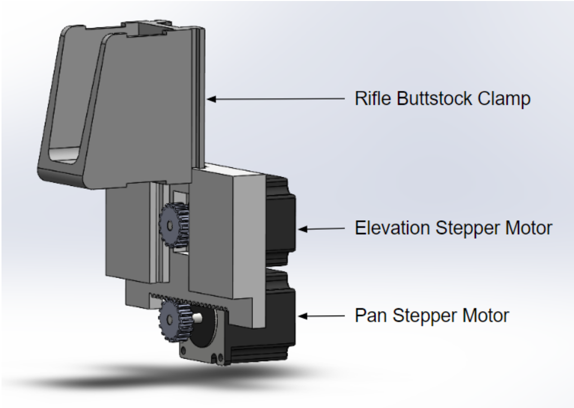

Figure 2.2.7 - Testbed Positional Control

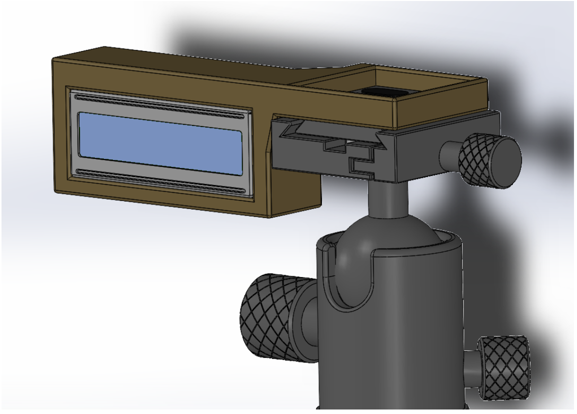

Figure 2.2.8 - Testbed Electronics

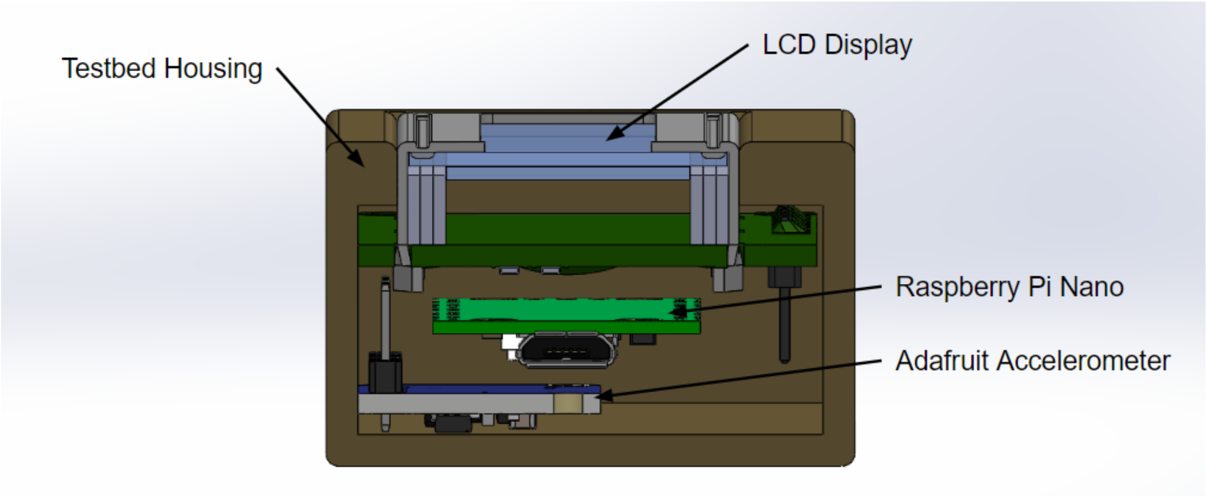

Figure 2.2.9 - Section View of the Testbed Electronics

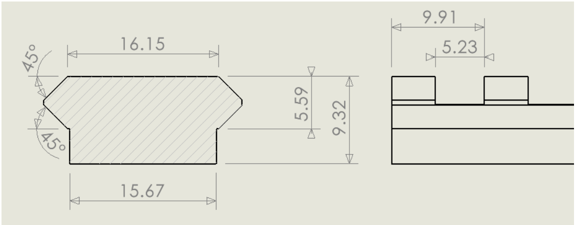

Figure 2.2.10 - Picatinny Rail Dimensions

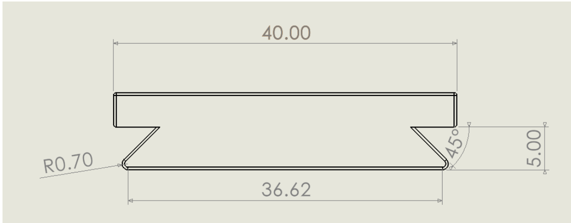

Figure 2.2.11 - Arca Swiss Rail Dimensions

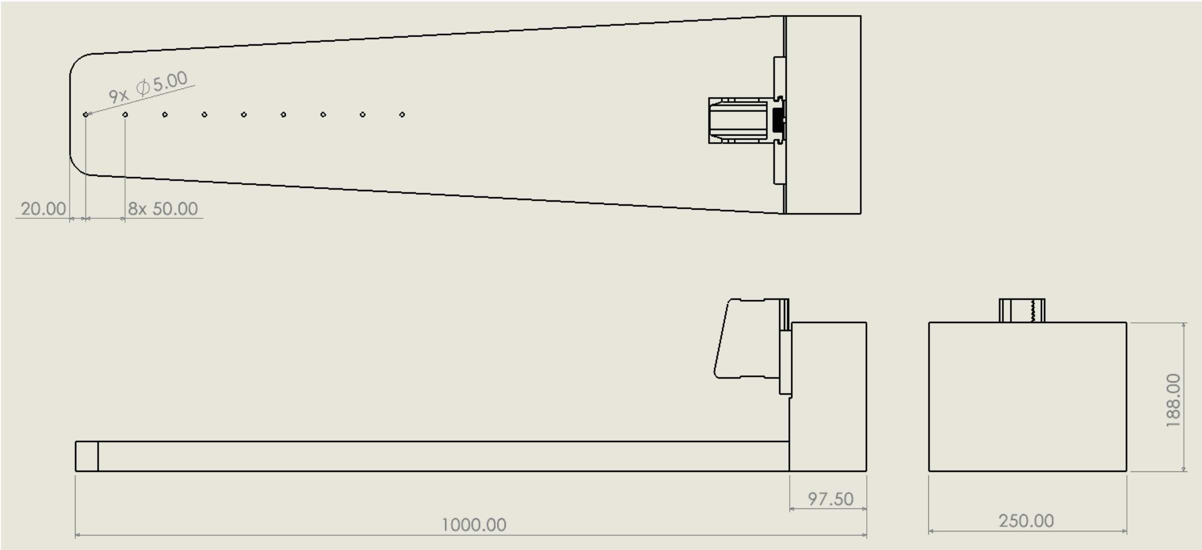

Figure 2.2.12 - Testbed Base Dimensions

2.3 Bill of Materials

Materials	Individual Cost ($)	Quantity	Total Cost ($)
DFR 0934 Transparent OLED Display	$53.51	1	$53.51
Raspberry Pi Pico Microcontroller	$5.63	2	$11.26
TF03-180 UART Rangefinder	$362.36	1	$362.36
ADXL -345 3-Axis Accelerometer	$25.17	2	$50.34
LCD-020N004L 20*4 LCD Display	$50.56	1	$50.56
Stepper Motor with Cable - ROB-09238 ROHS	$17.50	2	$35.00
Easy Driver - Stepper Motor Driver	$16.92	2	$33.84
Header Pins	$0.90	1	$0.90
Rangefinder Connector	$1.26	1	$1.26
2-inch x 4-inch x 8 ft. SPF Dimensional Lumber	$3.98	5	$19.75
EBL 2 Pack Rechargeable	$34.90	1	$34.90

Table 2.3.1 - Bill of Materials

3 IFOBS Design

3.1 Hardware Design and Electrical Specifications

3.1.1 General Rifle Optic Requirements

ID	Tag	Requirement Description
Req 3.2.01	A	Optic will be modular and integrate via standard rifle attachments
Req 3.2.02	A	Calibration and setup process is intuitive to the user
Req 3.2.03	B	Optic will weigh under 2.5 pounds
Req 3.2.04	B	Optic will be no larger in size than a conventional rifle scope
Req 3.2.05	B	Optic placement on the rifle will minimize torque load to the shooter
Req 3.2.06	C	Final product will cost under $500
Req 3.2.07	C	Optic will operate for longer than 100 hours with one battery charge
Req 3.2.08	C	Optic will display a high resolution point of aim that is easy for the shooter to identify the target
Req 3.2.09	C	Optic will be in compliance with military standards

Table 3.1.1.1 - General Rifle Optic Requirements

3.1.2 General Testbed Requirements

The following table outlines the general requirements of the testbed system.

ID	Tag	Requirement Description
Req 3.3.01	A	Testbed will hold a firearm securely under recoil
Req 3.3.02	A	Testbed will have two degrees of freedom
Req 3.3.03	A	Testbed will allow adjustment of firing position based off a closed loop feedback system with the optic
Req 3.3.04	A	Testbed will accurately measure and quantify performance of the optic
Req 3.3.05	A	Calibration process is intuitive to the user
Req 3.3.06	A	Testbed will control rifle orientation without human interaction
Req 3.3.07	A	Testbed motors must be have enough torque to maneuver 10lbs
Req 3.3.08	B	Testbed deployment will take less than 60 seconds
Req 3.3.09	C	Testbed will weigh under 10 pounds

Table 3.1.2.1 - General Testbed Requirements

3.1.3 Hardware Requirements

The following table outlines the general requirements of the system hardware.

ID	Tag	Requirement Description
Req 3.4.01	A	All optic hardware will be mounted on a firearm
Req 3.4.02	A	The rangefinder needs to operate over 100m
Req 3.4.03	A	Hardware will not obstruct the user
Req 3.4.04	B	All hardware will be powered by battery
Req 3.4.05	C	All hardware will be durable or protected from the elements
Req 3.4.05	C	Optic will compensate for parallax

Table 3.1.3.1 - Hardware requirements

3.1.4 Rangefinder Specifications

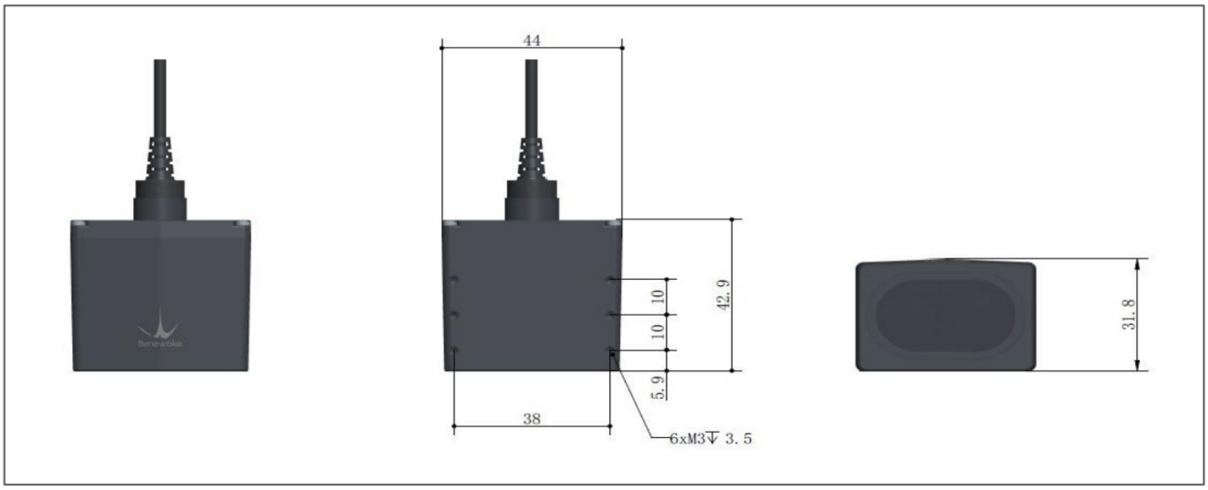

Figure 3.1.4.1 - Rangefinder Dimensions

Parameters	Specification
Operating Range	0.1 - 180m @90% reflectivity 0.1 - 70m @10% reflectivity 0.1 - 130m @90% reflectivity & 100K lux 0.1 - 50m @10% reflectivity & 100K lux
Accuracy	+/- 1% (10m and further)
Distance resolution	1cm
Frame rate	1hz~1000Hz (default 100Hz)
Repeatability	1σ: <3cm
Ambient light immunity	100K lux

Parameters	Specification
Operation temperature	-25~60C
Enclosure rating	IP67
Light source	LD

Table 3.1.4.1 - Rangefinder specifications

3.1.5 Optic display Specifications

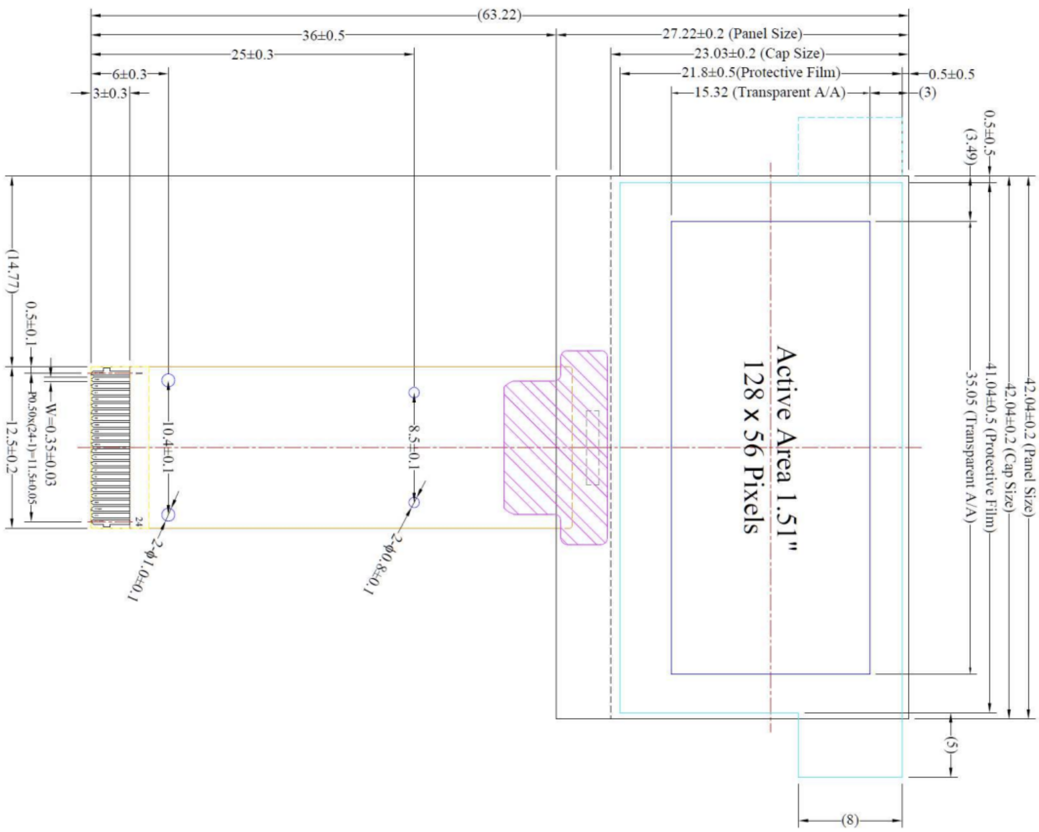

Figure 3.1.5.1 - Display Dimensions (top view)

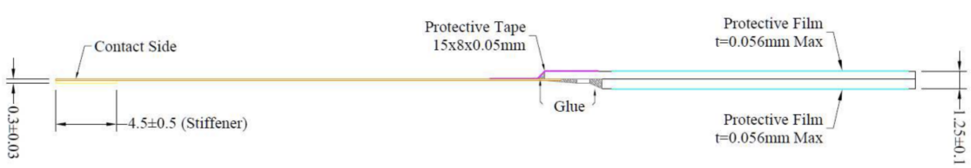

Figure 3.1.5.2 - Display Dimensions (side view)

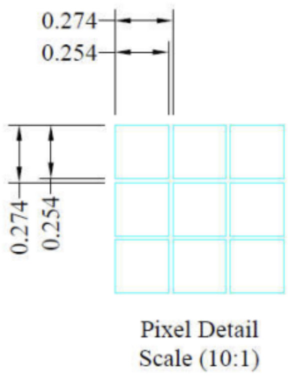

Figure 3.1.5.3 - Pixel Dimensions

Parameter	Specification
Display Mode	Passive Matrix
Display Color	Monochrome (Light Blue)
Drive Duty	1/56 Duty

Table 3.1.5.1 - OLED Display Specifications

Parameter	Specification
Number of Pixels	128 x 56
Module Size	42.04 x 63.22 x 1.25 (mm)
Panel Size	42.04 x 27.22 x 1.25 (mm)
Active Size	35.05 x 15.32 (mm)
Pixel Pitch	0.274 x 0.273 (mm)
Pixel Size	0.254 x 0.254 (mm)
Weight	TBD (g) +/- 10%

Table 3.1.5.2 - OLED Display Mechanical Specifications

3.1.6 Accelerometer Specifications

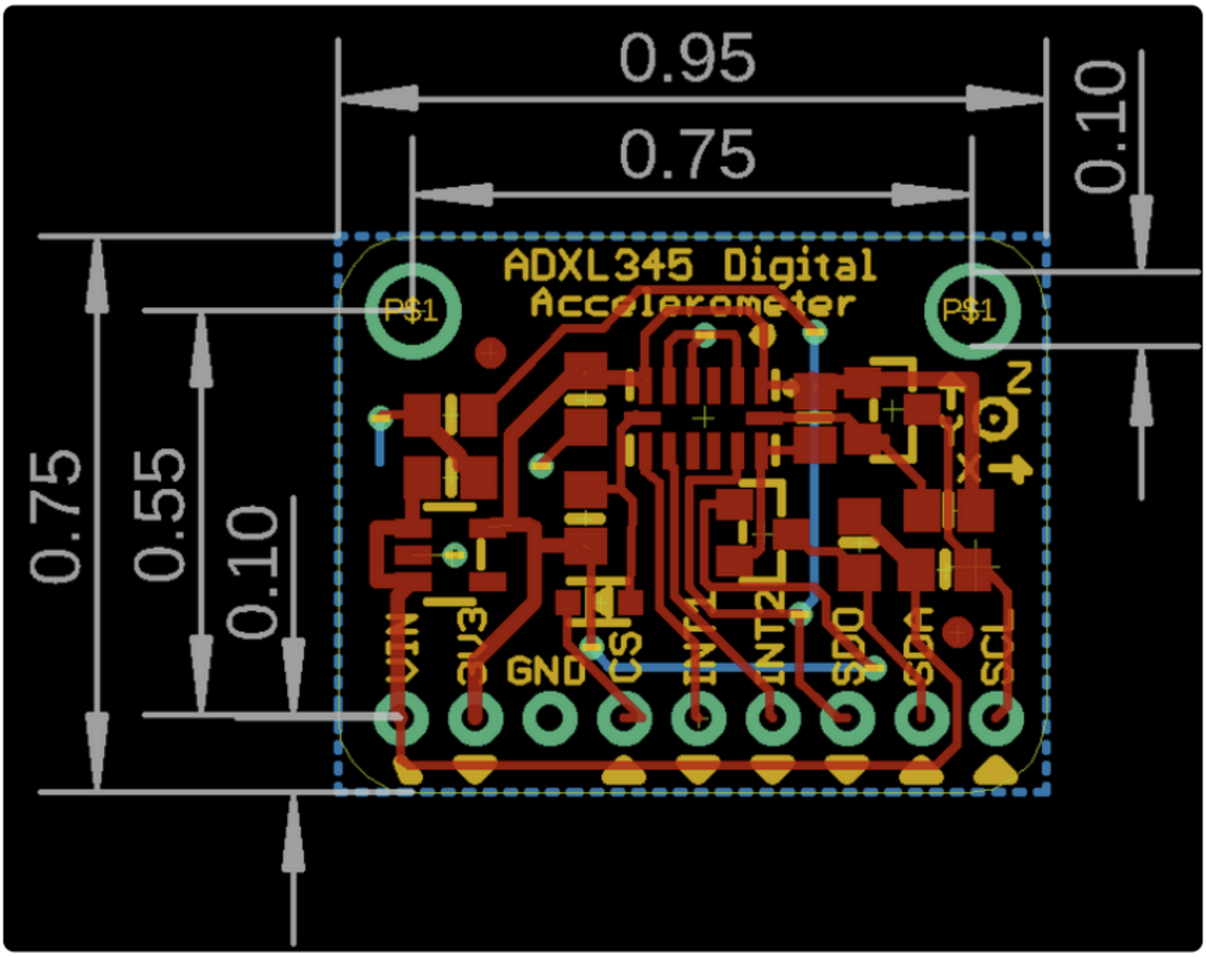

Figure 3.1.6.1 - ADXL345 Accelerometer Breakout Board Dimensions

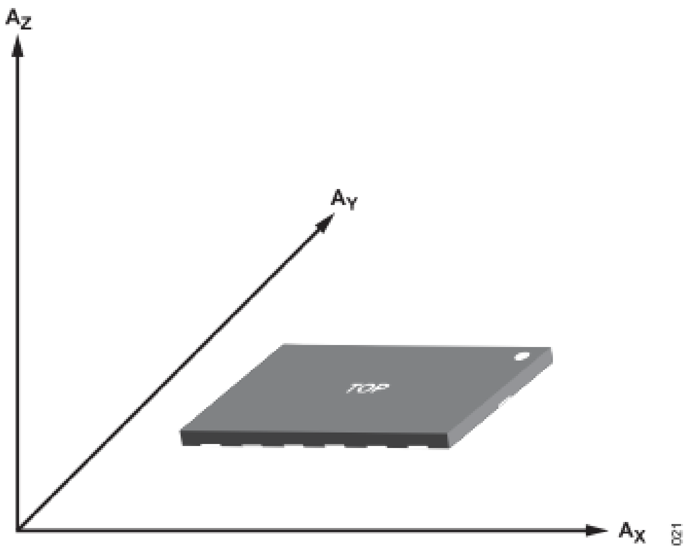

Figure 3.1.6.2 - Axes of Acceleration Sensitivity (Corresponding Output Voltage Increases When Accelerated Along the Sensitive Axis)

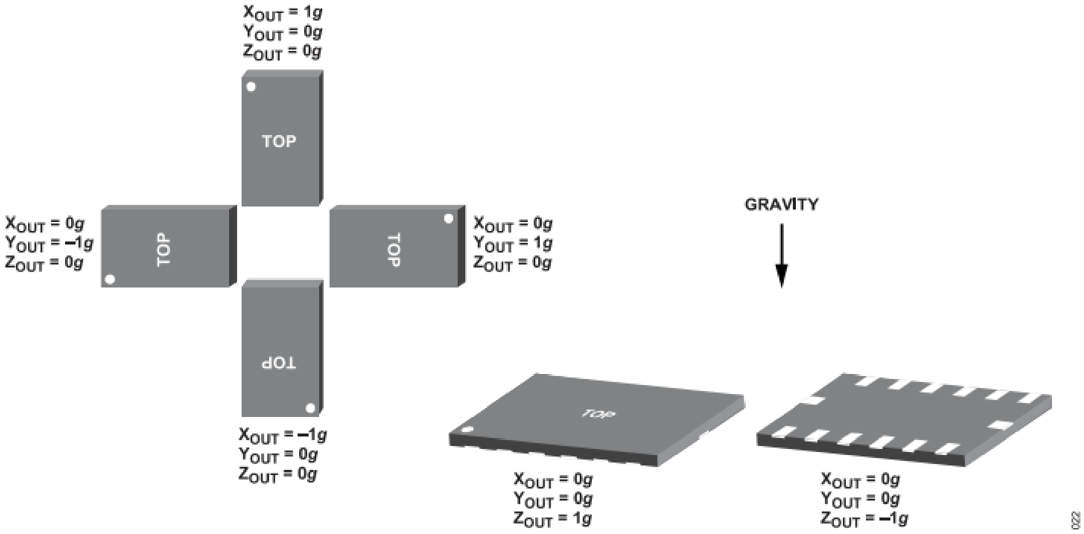

Figure 3.1.6.3 - Output Response vs. Orientation to Gravity

Parameter	Typical Value
Measurement range	+/- 2g
Nonlinearity	+/- 0.5g
Output Resolution	10 bits
Sensitivity at X_{OUT}, y_{OUT}, z_{OUT}	256 LSB/g
Sensitivity Deviation from Ideal Scale Factor at X_{OUT}, y_{OUT}, z_{OUT}	3.9 mg/LSB
Sensitivity Change due to temperature	+/- 0.01 %/C
0g Output for X_{OUT}, y_{OUT}	0 mg
0g Output for Z_{OUT}	0 mg
X-,Y-Axes Noise	0.75 LSB rms
Z-Axis	1.1 LSB rms
Output Data Rate (ODR)	0.1 to 3200 Hz
Output Change in X-Axis	0.20 to 2.10 g
Output Change in Y-Axis	-2.10 to -0.20 g
Output Change in Z-Axis	0.30 to 3.40g
Operating Voltage Range	2.5 V
Interface Voltage Range	1.8V
Supply Current	140 uA

Standby Mode leakage current	0.1 uA
Turn-On and Wake-Up Time	1.4 ms
Operating Temperature Range	-40 to +85 C
Device Weight	30 mg

Table 3.1.6.1 - Accelerometer Specification

3.1.7 Stepper Motor & Driver Specifications

ROB-0923 Stepper motor is a straightforward yet highly capable bipolar stepper motor equipped with a 4-wire cable for connection.The EasyDriver is a user-friendly stepper motor driver compatible with a wide range of devices. It requires a 6V to 30V power supply and can drive any voltage stepper motor. With its onboard voltage regulator, it offers precise motor control at either 5V or 3.3V. It supports bipolar motors and can be used with 4, 6, or 8 wire configurations.

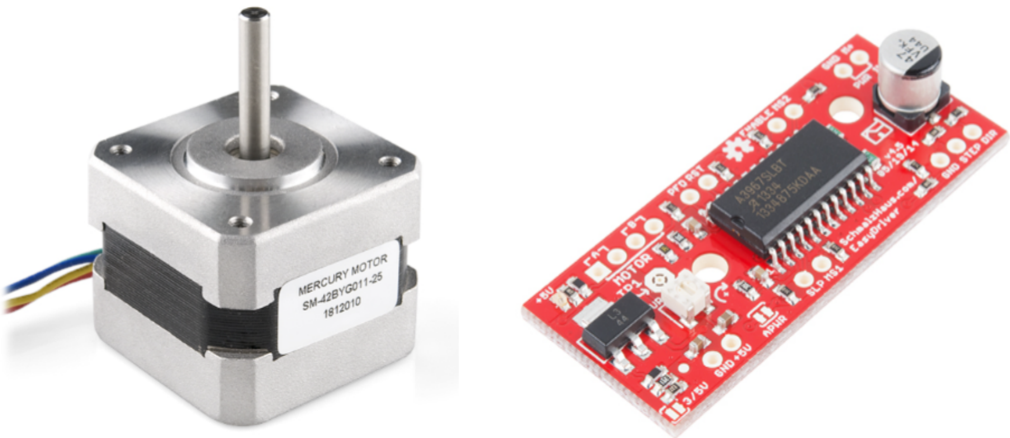

Figure 3.1.7.1 - ROB-0923 Stepper Motor and ROB-12779 Stepper Motor Driver

Parameter	Value
Step Angle (degrees)	1.8
Rated Voltage	12V
Rated Current	0.33A
Holding Torque	2.3kg*cm
Drive Shaft Diameter	5mm
Winding resistance	32.6 Ω
Winding inductance	48 mH
Max flux linkage	1.8 Vs
Maximum Detent Torque	0.016 N.M
Total inertia (kg.m.m)	3.5 Kg.m.m
Total friction (kg.m/s)	4 Kg.m/s
Motor Width	42mm (1.67”)

Table 3.1.7.1 - Stepper Motor ROB-09238 ROHS Specification

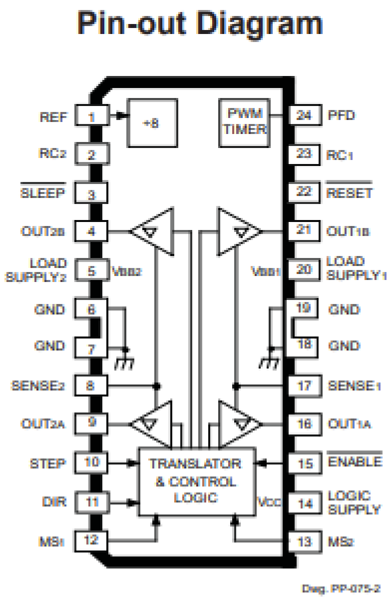

Figure 3.1.7.2 - Stepper Motor Driver ROB -12773 ROHS Pin-out Schematic

3.1.8 Power Needs and Battery Specifications

The Raspberry Pi is utilized to power all electronics components. The Raspberry Pi microcontroller requires a 5-volt input and can produce output voltages ranging from 1.8 volts to 5.5 volts. According to the power consumption, we plan to use the VGE Battery Pack for Raspberry Pi, 4000mAh, 5V 2.4A, Adhesive, Pi4 (USB-C) (USB-C) which is compatible with our existing controller and is rechargeable.

Figure 3.1.8.1 - VGE Battery pack attached to an encased raspberry Pi Controller

Parameter	Value
Manufacturer	VGE
Model Name	Raspberry Pi
Compatible Devices	Solar
Mounting Hardware	Battery Pack
Number of Items	1
Voltage	5 Volts
Batteries included	Yes
Batteries Required	Yes
Battery Capacity	4000 Milliampere Hour (mAh)
Battery Cell Composition	Lithium Polymer
Type of cable or wire	USB
Connector Type	USB

Table 3.1.8.1 - VGE Battery Pack 4000mAh, 5V, 2.4A specifications

3.1.9 Optic Circuitry Specifications

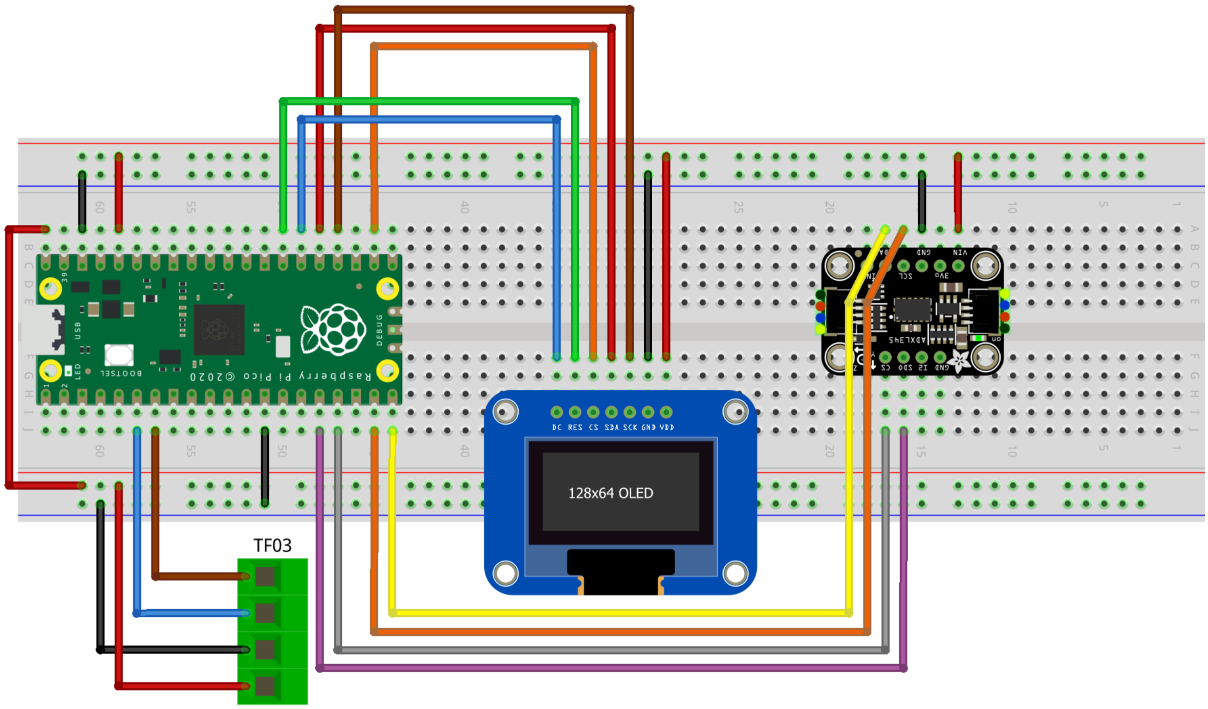

Figure 3.1.9.1 - Optic Wiring

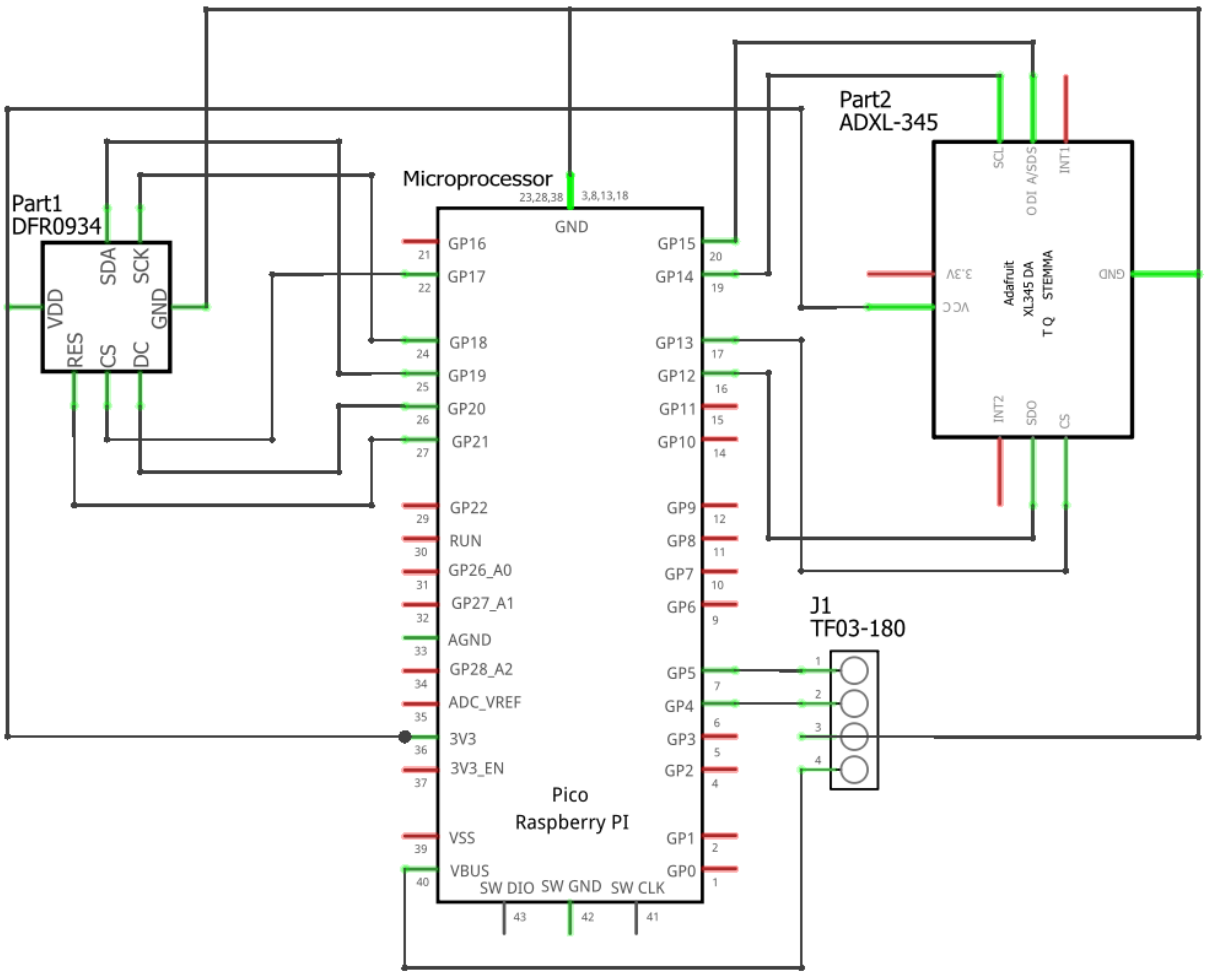

Figure 3.1.9.2 - Optic Schematic

Diagram Pin	TF03-180 Pin
1	UART_TX (Brown)
2	UART_RX (Blue)
3	GND (Black)
4	VCC (Red)

Table 3.1.9.1 - TF03-180 UART Pinout

3.1.10 Testbed Circuitry Specifications

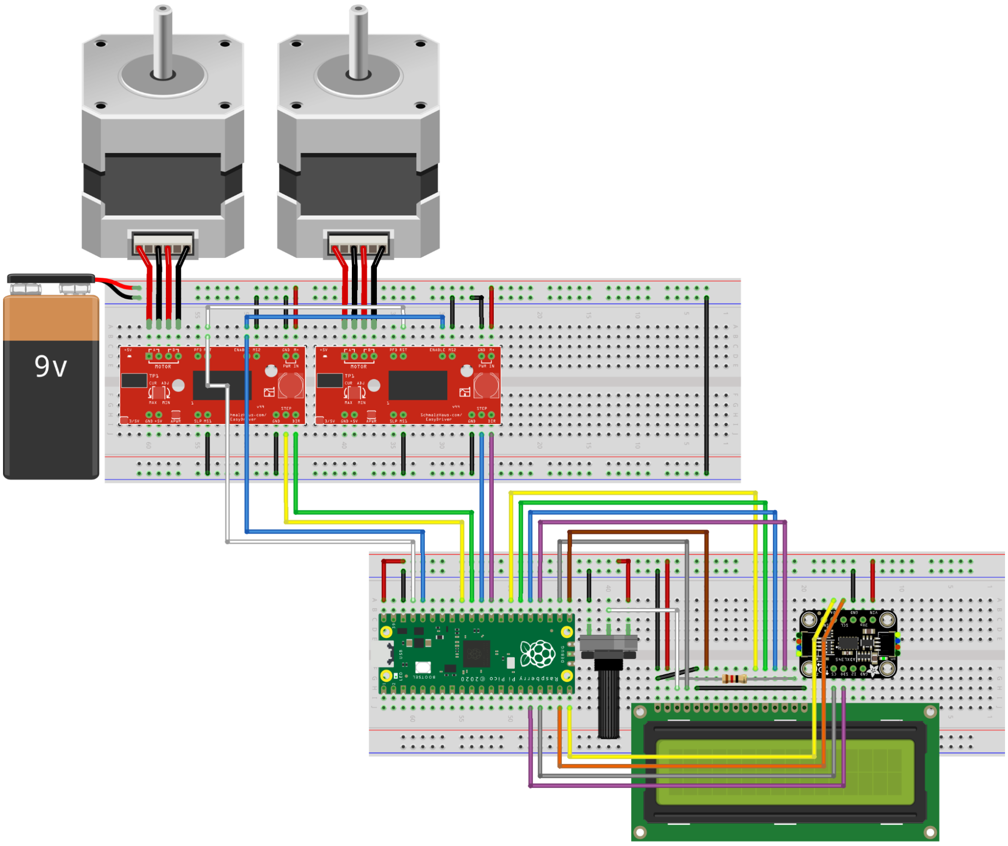

Figure 3.1.10.1 - Testbed Wiring

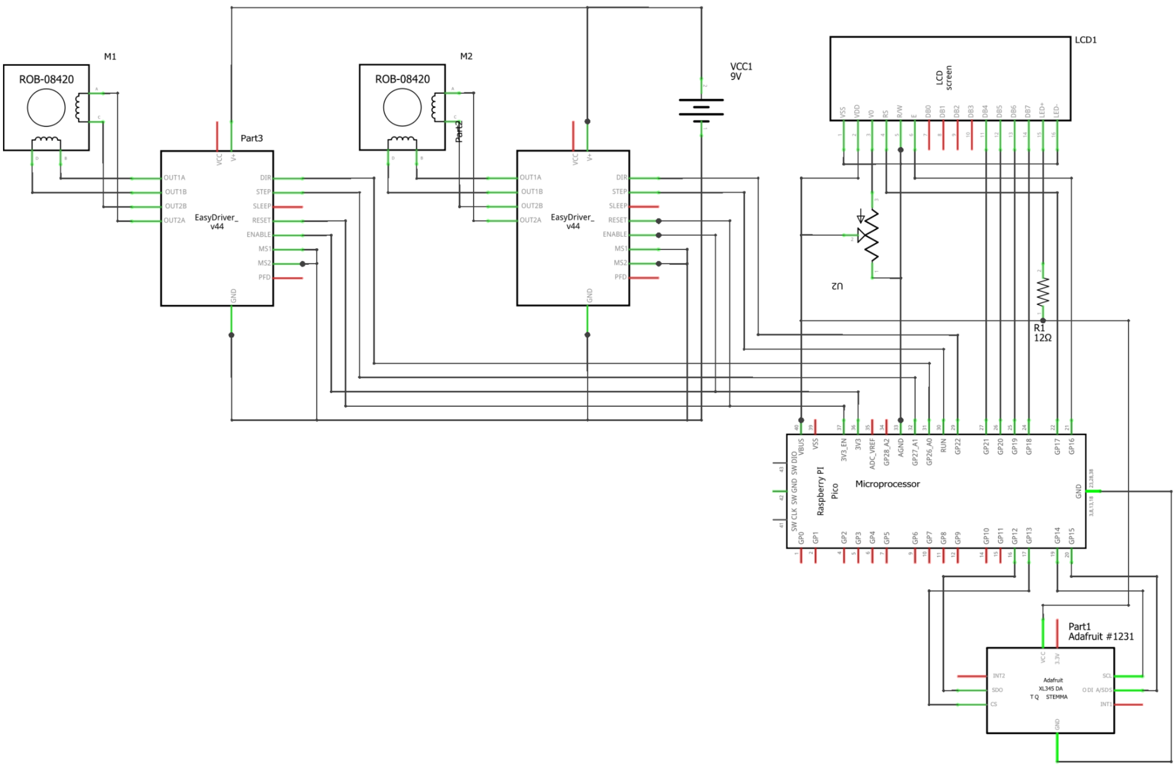

Figure 3.1.10.2 - Testbed Schematic

3.2 Software Design Specifications

3.2.1 Software Design Requirements

ID	Tag	Requirement Description
Req 3.5.01	A	Software will receive range data from a sensor
Req 3.5.02	A	Software will receive acceleration data from a sensor
Req 3.5.03	A	Ballistic calculations are done within the micro-controller
Req 3.5.04	A	Calculated point of aim will be output as pitch angle
Req 3.5.05	B	Software will receive tilt angle from sensor and added to calculation
Req 3.5.06	B	User can lock the current distance measurement
Req 3.5.07	B	Simple interface to display bullet trajectory to user
Req 3.5.08	C	Current distance and tilt are displayed to the user
Req 3.5.09	C	Calculation will take less than 100ms to be displayed to the user

Table 3.2.1.1 - Software Requirements

3.2.2 Cant and Elevation

The accelerometer is used to detect the direction of gravity. It is output in terms of the acceleration in the x, y and z-axes, which can be used to find the elevation and cant angles. A force diagram of the accelerometer viewed from the left and back is illustrated below:

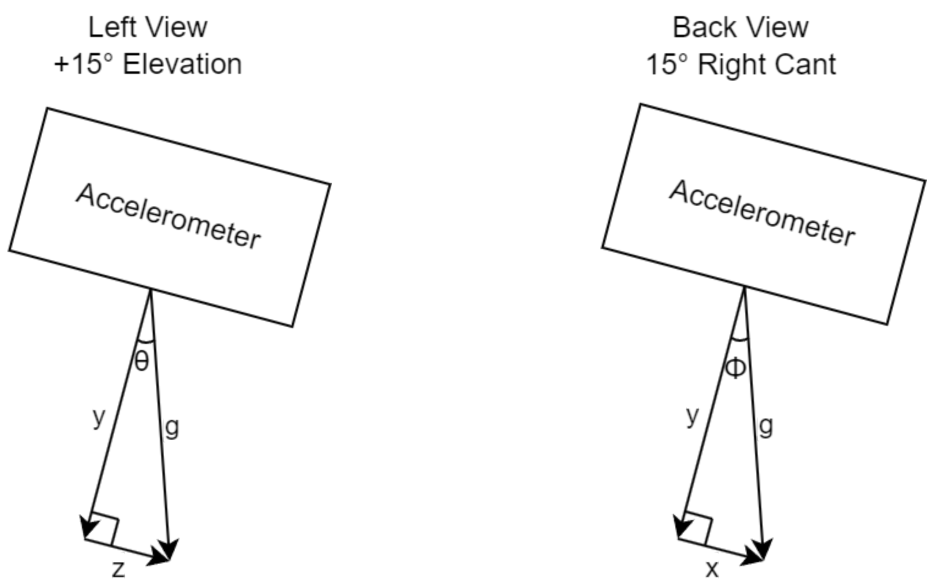

Figure 3.2.2.1 - Force of Gravity on the Accelerometer

Calculating the elevation and cant angles can be done by using the following trigonometry equations:

$$\theta = tan^{-1}(\frac{z}{y})$$

$$\varphi = tan^{-1}(\frac{x}{y})$$

Equation 3.2.2.1 - Elevation and Cant equations

The elevation angle is determined in this particular coordinate transformation by evaluating y and z direction. It calculates a point's vertical inclination with respect to the positive z-axis, often known as the positive y-z plane. The elevation angle, which represents how high or low the point is in regard to the reference plane, is calculated by taking the arctan of the ratio between the y-coordinate and the z-coordinate. As shown in the figure on the left, the elevation angle can be altered by considering the accelerometer's orientation and subsequent rotation upwards or downwards.

The cant angle, on the other hand, is evaluated as respect to x and y direction. A point's horizontal azimuthal rotation with respect to the positive x-axis is measured. The cant angle, which denotes the sideways tilt or rotation of the point along the x-y plane, is calculated by taking the arctan of the difference between the y-coordinate and the x-coordinate. As shown in the figure on the right, the cant angle can be altered by considering the accelerometer's orientation and subsequent rotation left or right.

3.2.3 Bullet Trajectory

The bullet trajectory equations will be a crucial part of our project's ballistics computations. Using these equations, we can precisely estimate a bullet's trajectory while accounting for variables like velocity, initial bullet angle, and the effects of gravity. The bullet trajectory equations, which are derived from the laws of motion, give us information on the bullet's trajectory and allow us to precisely compensate for elevation and range. Starting with the following equations to determine the bullet trajectory equation from the equations of motion:

Displacement in the x-direction:

$$x = V_x t = v_0 cos(\theta)t$$ [2]

Equation 3.2.3.1 - X-displacement equation

Displacement in the y-direction:

$$y = h + V_y t - \frac{1}{2}gt^2 = h + v_0 sin(\theta)t - \frac{1}{2}gt^2$$ [2]

Equation 3.2.3.2 - Y-displacement equation

Here, x stands for the distance traveled horizontally, y for the distance traveled vertically (drop), v_0 for the velocity, for the beginning bullet angle (elevation angle), t for the amount of time passed, h for the initial height of the bullet, and g for the acceleration brought on by gravity [3].

We can isolate t in the x-direction equation and substitute it into the y-direction equation to get rid of t and get the bullet trajectory equation. Let's go over each step:

From the x-direction equation, we can solve for t:

$$t = \frac{x}{V_x} = \frac{x}{v_0 cos(\theta)} \quad [2]$$

Now, substitute this expression for t in the y-direction equation:

$$y = h + v_0 sin(\theta) * (\frac{x}{v_0 cos(\theta)}) - \frac{1}{2} g (\frac{x}{v_0 cos(\theta)})^2 \quad [2]$$

Simplifying the equation further:

$$y = h + x * tan(\theta) - \frac{gx^2}{2v_0^2 cos^2(\theta)} \quad [2][3]$$

Equation 3.2.2.3 - Bullet trajectory equation

The equation above is the derived bullet trajectory equation. In this equation, y stands for the bullet's vertical displacement (drop), h for its initial height, x for its horizontal distance, for its initial angle (elevation angle), g for its acceleration by gravity, v_0 for its velocity [3]. By using this equation, we can calculate the trajectory of the bullet over a range of distances and make the necessary corrections for precise shooting.

3.2.4 Optic Flowchart

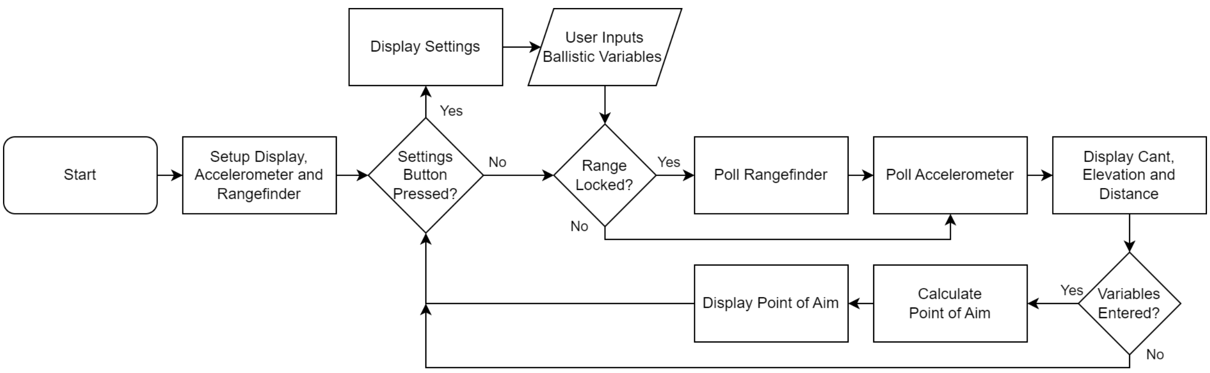

Figure 3.2.4.1 - Flowchart of the optic's software

3.2.5 Testbed Flowchart

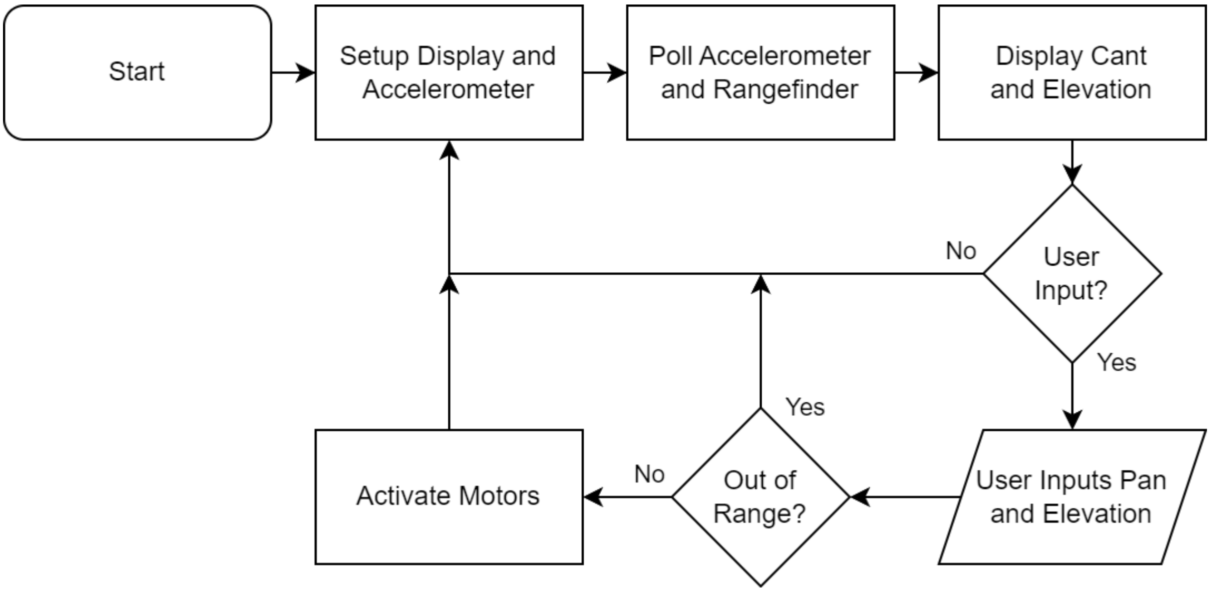

Figure 3.2.5.1 - Flowchart of the testbed's software

4 Conclusion

In conclusion, the design specifications for the advanced rifle scope presented in this document demonstrate the careful consideration given to enhance shooting accuracy, usability, and durability. The design choices discussed, including system overview and IFOBS design, were made with the aim of providing shooters with a reliable and effective tool for improved targeting and shooting performance. By incorporating high-quality materials, and intuitive controls, the designed scope offers a practical and user-friendly solution. Throughout the design process, feedback from experienced shooters and considerations of real-world shooting scenarios played a crucial role in refining the design requirements. The comprehensive set of design choices in this document reflect the commitment to delivering a high-performance rifle scope that meets the needs of shooters while ensuring reliable and precise aiming capabilities.

5 References

[1] Mizokami, K. (2021) *The U.S. Army is testing a ‘guaranteed hit’ smart scope for its rifles*, *Popular Mechanics*. Available at: https://www.popularmechanics.com/military/weapons/a30720528/us-army-rifle-smash-scope/ (Accessed: 09 July 2023).

[2] Pamula, H. (2023) *Trajectory calculator*, *Projectile Motion*. Available at: https://www.omnicalculator.com/physics/trajectory-projectile-motion (Accessed: 08 July 2023).

[3] Hoyos, L. (2022) *Trajectory calculator*, *Projectile Motion*. Available at: https://www.calctool.org/kinetics/trajectory-projectile-motion (Accessed: 08 July 2023).

[4] S. Shepheard, “The Complete Aluminum 3D printing guide,” 3DSourced, https://www.3dsourced.com/3d-printer-materials/3d-printing-aluminum-guide/ (accessed Jul. 10, 2023).

[5] K. DeVries, “Fused deposition modeling (FDM) 3D Printing Service,” Xometrys RSS, https://www.xometry.com/capabilities/3d-printing-service/fused-deposition-modeling/?hsa_acc=3789459769&hsa_cam=326820211&hsa_grp=1245747074241507&hsa_ad=&hsa_src=o&hsa_tgt=kwd-77859496047528%3Aloc-4056&hsa_kw=PLA+3d+printing&hsa_mt=e&hsa_net=adwords&hsa_ver=3&msclkid=94458426bf671a6134e5e08a6f4307e4&utm_source=bing&utm_medium=cpc&utm_campaign=PB%3AM%7CNT%3ASN%7CAN%3AManufacturing%7CCN%3A3D_Printing_Exact&utm_term=PLA+3d+printing&utm_content=PB%3AM%7CNT%3ASN%7CAN%3AManufacturing%7CCN%3A3D_Printing_Exact%7CPN%3APLA (accessed Jul. 10, 2023).

[6] M. Cox, “The Army is eyeing this advanced fire-control system for its next-generation squad weapon,” Task & Purpose, https://taskandpurpose.com/news/next-generation-sqaud-weapon-fire-control-system-contract/ (accessed Jul. 10, 2023).

[7] “Ballistic trajectory calculator,” ShooterCalculator.com - Online Ballistics Calculator, https://shooterscalculator.com/ballistic-trajectory-chart.php?t=b2dbdb7d (accessed Jul. 10, 2023).

6 Appendix A: Design Alternatives

6.1 Material Choices

The Testbed and optic will be made from aircraft-grade aluminum in the commercial production version. Aluminum is versatile, lightweight, flexible, and can be manufactured via laser powder bed fusion-based techniques including SLM (selective laser melting) and DMLS (direct metal laser sintering). These characteristics satisfied the following structural requirements: **Req 3.2.09, Req 3.3.09, Req 3.4.05.**

Due to an expensive cost of aluminum powder at $80 to $120 per kilogram [4], the test bed and optic will be constructed using a combination of traditional PLA and Spruce-Pine-Fir (SPF) wood.PLA cost $15 to $30 per kilogram [5] and 2-inch x 4-inch x 8 ft. SPF Dimensional Lumber can be bought for $3.98 at home depot. These design alternatives will significantly lower cost of development in the Proof of Concept and Engineering Prototype stages.

6.2 Rangefinder Alternatives

From our market research, the current cutting edge technology that is being developed consists of a 1000m rangefinder[6]. While 1000m rangefinders exist on the market primarily for golfing use, these sensors are extremely inaccurate for such a precision application. Other budget market options such as the LightWare LW20/C and the DFRobot SEN0366 follow the same trend of sacrificing range for accuracy. An accurate and precise optic rated for 1000m is not feasible as it would significantly cut into our cost and power budget.

Instead, we have constrained our project requirements to 100m. (**Req 3.4.02**) This is chosen as .22 LR ammunition will experience a bullet drop of around 6 inches [7] providing sufficient drop to validate our product functionality. Additionally 100m is the common specification rating for most rifle attachments. The TF03-180 was chosen for reasonable accuracy with a maximum rating of 180m. This allows us to further validate the ballistics calculation by testing at ranges between 100m and 180m. The range finder is one of the cheapest on the market costing $400 and satisfying our budget requirements. (**Req 3.2.06**)

6.3 Rifle and Testbed Orientation Determination

The rifle's pitch and yaw can be determined through a couple of ways. An accelerometer can be used to measure the earth’s gravity and through coordinate conversion the orientation of the sensor can be measured. A gyroscope can measure earth’s magnetic field and similarly obtain the rifle’s orientation. A gyroscope experiences gyro drift and is not suitable for our applications. An accelerometer is thus chosen for our application. While the accelerometer also experiences drift, this effect will be minimized since our product will be primarily stationary.

A gyroscope will be added in the production version or the prototype stage based on development budget. The addition of the gyroscope allows for the implementation of a Kalman filter which will increase orientation accuracy and product reliability in mobile applications.

7 Appendix B: Test Plan

The following section provides deliverables for proof of concept demonstration and various test procedures regarding product safety and efficacy.

7.1 Proof of Concept Deliverables

This section outlines the key functionalities of our optic that will be presented at the proof of concept poster presentation in August 2023:

- The optic will detect the range of the target and the position of the firearm
- The calculated point of aim will be given as the angle of elevation
- The optic will be battery powered and mounted on a prop firearm
- The testbed will hold a prop firearm securely
- The testbed will allow adjustment and locking of two degrees of freedom, elevation and cant
- The testbed will display the firearm’s cant and elevation angles
- The testbed motors successfully maneuver the rifle based off an input pitch and yaw angles
- The testbed has software and/or hardware limitations to safely constrain the rifles firing angles.

7.2 Key Problems to be Addressed

In order to achieve the proof of concept product listed above, these key problems need to be addressed:

- Precise alignment of the optic along with its sensors on the firearm
- Testing the ballistics calculation
- The rangefinder’s maximum range
- Compatibility between components

7.3 Testing Procedure

The following procedures outline steps for functionality and safety verification. Tester should perform the steps in the following order.

Test: Oled Display	**Time:** _________	**Date:** _________
Test Procedure: - Tester will connect accelerometer to the pi - Tester will the hello world test code.		
Expected Outcome: Hello World text is displayed on the screen		
Observed Outcome:		
Comments:		
P/F: ☐ Pass ☐ Fail	**Tester Name**: ______________________	

Test: Accelerometer	**Time:** _________	**Date:** _________
Test Procedure: - Tester will connect accelerometer to the pi - Tester will lay the accelerometer flat and run the calibration sequence - Tester will tilt accelerometer +/- 90 degress in the pitch and roll axis		
Expected Outcome: Pitch and roll is displayed. No measurement drift is observed.		
Observed Outcome:		
Comments:		
P/F: ☐ Pass ☐ Fail	**Tester Name**: ______________________	

Test: Range Finder	**Time:** __________	**Date:** __________
Test Procedure: - Tester will connect rangefinder to the pi - Tester will aim range finder at objects at 25m, 50m, 100m - Tester will record the displayed distance versus the true distance		
Expected Outcome: Range finder should be within 1% of true distance.		
Observed Outcome:		
Comments:		
P/F: ☐ Pass ☐ Fail	**Tester Name**: ________________________	

Test: Testbed Motors	**Time:** __________	**Date:** __________
Test Procedure: - Tester will connect motors to the pi - Tester will attach 5lbs test load to motors. - Tester will run the motors +/- 90 degress in the pitch and roll axis.		
Expected Outcome: Test load turns the correct amount. No measurement drift observed. Software sucessfuly locks motors at +/- 45 degrees.		
Observed Outcome:		
Comments:		
P/F: ☐ Pass ☐ Fail	**Tester Name**: ________________________	

Test: Ballistic Prediction	**Time:** _________	**Date:** _________
Test Procedure: - Tester will connect all optic electronics (display, rangefinder, aceelerometer) to the pi. - Tester will laze an object at 100m - Tester run the ballistic prediction sequence		
Expected Outcome: A point of impact dot perdiciton is visible on the display. A reccomended pitch and yaw adjustment is displayed on the display.		
Observed Outcome:		
Comments:		
P/F: ☐ Pass ☐ Fail	**Tester Name**: ______________________	

Test: Testbed input	**Time:** _________	**Date:** _________
Test Procedure: - Tester will connect testbed and optic microcontrolers - Tester will verify data transmission is functional - Tester will transmit prediction Pitch and Yaw from optic to testbed		
Expected Outcome: Testbed turns based on the received pitch and yaw.predictions.		
Observed Outcome:		
Comments:		
P/F: ☐ Pass ☐ Fail	**Tester Name**: ______________________	