EECS
Electrical Engineering &
Computer Science

The LiDAR Whitepaper

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1 Introduction

Approximately 1 month ago, the Team 1280 Electrical Engineering and Computer Science Department (henceforth referred to as just EECS), an independent organ of the Team 1280 official organization which operates extrajudicially and without congressional oversight, requisitioned a LiDAR capable of generating a 3-D depth map of the area ahead in order to supplement and enhance the **BozoVision** subroutine with additional sensory input. However, a SNAFU (or deliberately malicious incompetence) led to the acquisition of a 1-D LiDAR sensor manufactured by GARMIN. This LiDAR acts as a glorified USS rangefinder, and has a resolution of just 1cm. This LiDAR, out of the box, would not have been able to support anything approximating a depth map that met EECS's stringent specifications and standards. Despite numerous protests against the purchase of this 1-D LiDAR (which has a market value of $160 USD and incurs a significant opportunity cost), EECS was ultimately forced to acquiesce in the purchase of the LiDAR.

1.1 In this paper

We will discuss the planned modifications and additions that will allow us to utilize this 1-D LiDAR to its full capabilities and achieve our goal of generating a depth map (now scaled down to simply a 2-D map instead of a full 3-D One).

2 LiDAR Specifications

The 1-D LiDAR we received was the LiDAR Lite v3, manufactured by GARMIN, and distributed by the multinational arms conglomerate AndyMark under the SKU am-3829. Despite its severely limited resolution, it is saved by its otherwise impressive technical specifications.

2.1 Technical Specs (selected)

Spec	**Details**
Transmit power (laser)	1.5Watts peak 14mm @ 3amps drive, 75 µm single stripe laser junction
Transmit power (LED)	200mW within ± 3° beam @ 1amp
Operational Range	1-40 meters (able to sense the presence of objects under 1 meter but not ascertain the exact distance)
Measurement Rate	Up to 500 readings per second

2.2 Notable Specs

The capabilities of most interest for our purposes are the operational range and measurement rate. With a reading of up to 500 times per second, we should be able to use it to more interesting ends than simply reading a distance up ahead in one direction.

3 Introducing the Rotating LiDAR

3.1 The Rotating LiDAR

As mentioned, the 1-D LiDAR's impressive refresh rate and measurement distance makes it an ideal candidate for EECS's latest innovation: the rotating LiDAR. In order to circumvent the limitation of the LiDAR to its singular direction of measurement, we've designed a system in which the LiDAR rotates at a high angular velocity (up to multiple times per second) in order to generate an approximate 2-D depth map of the surroundings. We believe this to be possible due to the incredibly fast update rate of the LiDAR. Ideally, it should be able to rotate at least once per second, and take at least 360 readings (one for each degree traversed) to create an image with an angular resolution of 1 degree ($\frac{360°}{300 \text{ Samples}}$), which is enough fidelity for our purposes.

3.2 A Brief Backstory

After much tumult, EECS has at long last produced its first iteration of prototype designs for the rotating mount that the 1-D LiDAR will be attached to. This project has been under top secret development at an EECS blacksite for over 2 weeks, but official 1280 Leadership has been running interference operations to prevent the rotating LiDAR from being created. Our original contract with the CAD subteam has been severed after enemy counterintelligence led CAD to believe that the plans for the rotating LiDAR had been cancelled and that we had re-specced to a vertical mount with a tiny degree of angular freedom. This was a major setback in our prototyping, but EECS remained undeterred. After forming its own dedicated and autonomous CAD subdivision free from Team 1280 Leadership's oversight and actively resisting Team 1280 mandated audits, EECS was able to create the first prototype for the rotating LiDAR design.

3.3 Feasibility Report

Before delving into the specific details behind the design of the rotating LiDAR, it may be helpful to first describe the reasons as to why we believe it is a viable design.

3.3.1 Introduction

The approach to creating an approximate 2-D depth map using a 1-D LiDAR by rotating it and matching up distance readings with encoded angles is feasible and is a known method in robotics and autonomous systems for generating 2 dimensional and even 3 dimensional maps. This method, often referred to as a LiDAR scanner or rotating LiDAR system, can provide a detailed view of the environment by scanning it in a planar fashion.

3.3.2 Hardware

- **LiDAR Sensor**: Capable of measuring distances up to 40 meters and operating at up to 500Hz for reliable performance.
- **Motor with Hall-Effect Encoder**: To precisely control the rotation of the LiDAR and measure its angle with high accuracy. The encoder's resolution should be high enough to accurately associate each LiDAR reading with a specific angle. A hall effect encoder should be able to meet this requirement as they are known to be highly accurate and precise.

3.3.3 Software and Data Processing

- **Data Synchronization**: Implement a method to accurately synchronize the distance measurements from the LiDAR with the angular position data from the encoder. This is crucial for mapping the distance data accurately onto a 2D plane.
- **Angular Resolution**: Determine the angular resolution you need. The speed of the motor and the LiDAR's sampling rate will dictate the angular resolution of your scan. For instance, at 360Hz, if you rotate the LiDAR 360 degrees in one second, you'll get an angular resolution of 1 degree ($\frac{360°}{300\text{ Samples}}$).
- **Data Processing and Mapping**: Develop software to process the synchronized distance and angle data, converting polar coordinates (angle, distance) into Cartesian coordinates (x, y) for each point. This step is essential for creating the 2D depth map.

3.3.4 Considerations

- **Scan Speed vs Resolution**: There's a trade-off between the scanning speed and the resolution of your depth map. Higher resolution scans (more points per rotation) will require slower rotation speeds or higher LiDAR sampling rates.
- **Obstacle Detection and Mapping Accuracy**: The accuracy of obstacle detection will depend on the LiDAR's precision, the encoder's accuracy, and the processing algorithm's capability to handle noise and outliers.
- **Field of View**: The field of view of your 2D map will be determined by the LiDAR's maximum distance capability and the angular coverage of the rotation. Full 360-degree rotation is ideal for all-around coverage.
- **Mechanical Design**: Ensure the mechanical design is robust enough to handle the rotation speed and provides a stable platform for the LiDAR to avoid vibration-induced inaccuracies.
- **Electrical Design**: Depending on our wiring setup for the LiDAR, we may have a situation where we are unable to avoid the cables being tangled around the motor after rotations. To alleviate this, we may be able to utilize an oscillating design where the LiDAR will alternate between turning 360° repeatedly alternating between clockwise and counter-clockwise to avoid any tangling. The downside to this approach is that we will likely be unable to sustain a continuous angular velocity and therefore make our intermittent angular extrapolations difficult (discussed in **Section 4.2**).

3.3.5 Implementation Steps

- **Integration**: Integrate the LiDAR with the motor and encoder, ensuring stable and accurate rotation.
- **Calibration**: Calibrate the system to ensure that distance measurements are accurately matched with their corresponding angular positions.

- **Software Development**: Develop software for data acquisition, synchronization, processing, and visualization.
- **Testing and Optimization**: Test the system in various environments to optimize the scanning parameters and improve the accuracy and resolution of the 2D depth map.

3.3.6 Conclusion

This method has been successfully implemented in various applications, including autonomous vehicles, robotics navigation, and environmental scanning. With careful design and calibration, we can achieve a reliable 2-D mapping system using our 1-D LiDAR.

4 Our Design

4.1 Introduction

Now, we can finally discuss our proposed design for the 2-D Rotating LiDAR. As mentioned previously, the newly-autonomous EECS CAD subdivision has created the first prototype design for the rotating mount.

4.2 Hardware Details

The design utilizes a Pololu Micro Metal Gearmotor which operates at 12V of DC current and has a 30:1 gear ratio metal gearbox. It has an extended motor shaft perfect for stable mounting of the LiDAR and can rotate at up to 1100 RPM, or around 18.3 times per second, which should be more than enough for our needs. It is lightweight and has a small form factor, as well as a power draw of merely 80mA and 0.39 kg · cm of torque. Coupled with this, we will use a Pololu magnetic quadrature hall-effect encoder designed specifically for our Micro Metal Gearmotor, which will provide us with the necessary angle measurements for the LiDAR. This encoder is limited in that it only reads 12 counts per revolution (aka at 30° intervals in one 360° rotation), but we should be able to account for this in our code by calculating the time it takes for each 30° increment and extrapolating approximate angle data for measurements taken in between (this also follows the Google design ethos of using terrible hardware and fixing everything with black magic software).

Figure 1: The motor

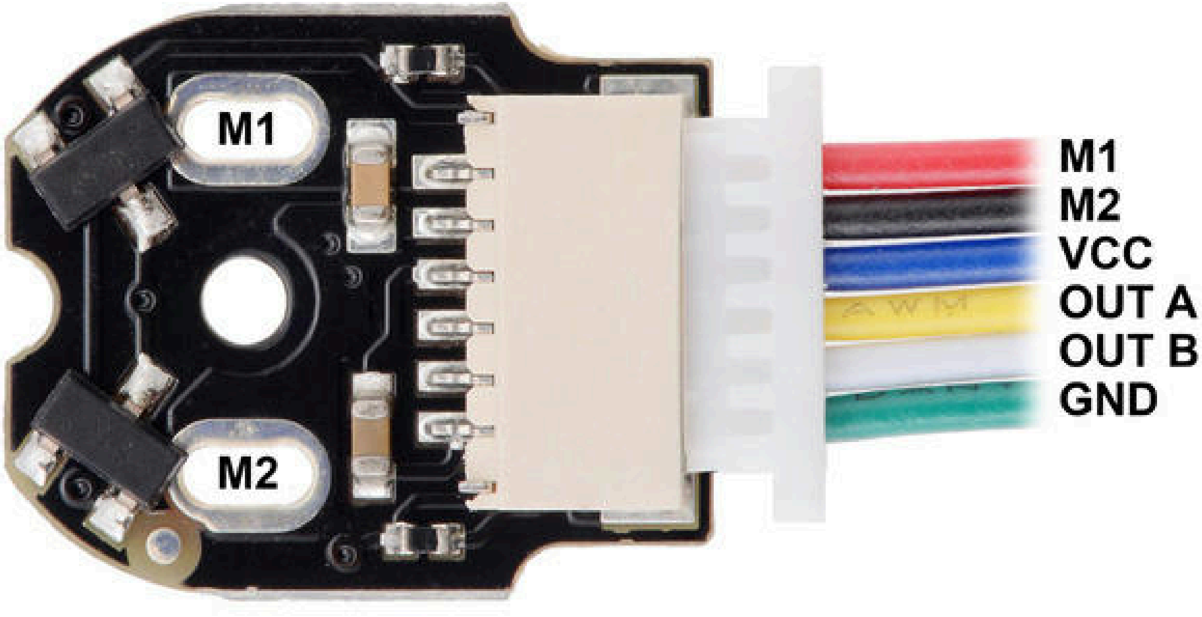


Figure 2: The encoder

4.3 Our Custom LiDAR Mount

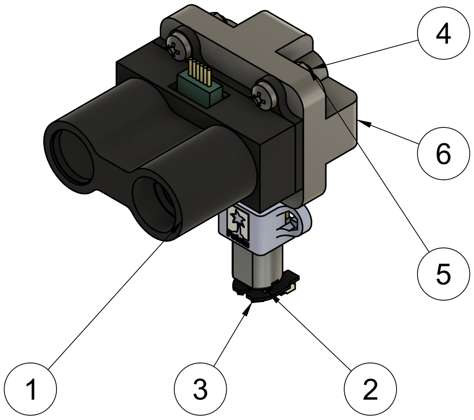
Our CAD subdivision has produced designs for a LiDAR mount which will allow the LiDAR to be affixed to the rotating shaft of the motor. The design of this mount should be finalized and then manufactured by our state of the art 3D printers. You can view engineering drawings of our mount on the following page.

4.4 A Brief Word on FRC Legality

Our motor and its encoder seems to be legal for official use. As per the FRC guidelines:

> Motors integral to a COTS (commercially off-the-shelf) sensor (e.g. LIDAR, scanning sonar, etc.), provided the device is not modified except to facilitate mounting

are considered legal.



Parts List

Item	Qty	Part Name	Material
1	1	LiDAR Lite v3 v3	
2	1	Micro Motor w/ 1086 Bracket v2	Steel
3	1	Magnetic Encoder v1	Steel
4	4	Raised Cheese Head Screw DIN 7985 - M3.5 x 14 - H Steel 4.6 Plain v1	Steel 4.6, Plain
5	5	Hexagon Thin Nut DIN 439-2 - M3.5 x 0.6 Steel 6 Plain v1	Steel 6, Plain
6	1	Bracket	Steel

Dept. EECS	Technical reference	Created by Youwen Wu 2/5/2024	Approved by
		Document type	Document status
		Title LiDAR Mounting Bracket	DWG No.
			Rev. Date of issue Sheet 1/3

Figure 3: Parts Diagram

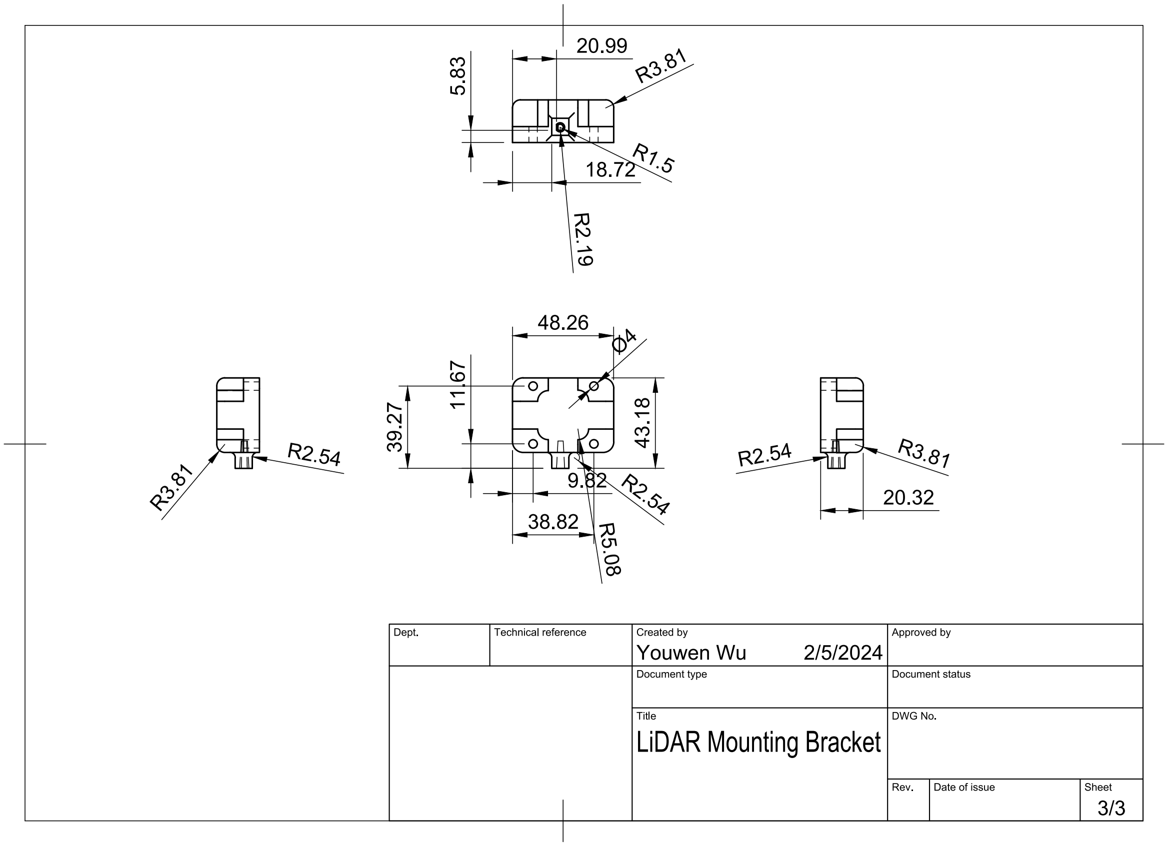


Figure 4: Engineering Drawings

5 Conclusion

Following the finalization of the LiDAR design, we should be able to manufacture and develop it by following the steps outlined above in **Section 3.3 (Feasibility Report)**. This should be a top EECS priority and we must operate independently and extrajudicially as necessary to create the rotating LiDAR as fast as possible as it is essential for our **BozoVision** capabilities. In the inevitable event that Matthew discovers our plans to install the rotating LiDAR, we should aim to have completed as much progress as possible in order to exploit the Sunk-Cost fallacy and pressure him to include the rotating LiDAR in our final designs.