University of Moratuwa

Department of Electronic & Telecommunication Engineering

EN2160 - Electronic Design Realization

(Report 01)

Design Methodology

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Contents

1. Abstract

Design and develop a 3D LiDAR scanner for detailed 3D map creation, targeting various applications. This scanner makes use of only one laser scanner and combines it with a cylindrical cam mechanism to conduct horizontal and vertical movements. The design above brings down the cost drastically compared to commercial LiDAR scanners, majorly working with multi-laser modules. This economical route, however, comes at the slight cost in the speed of operation compared with the industrial versions.

This project involves the developing of precise and robust mechanical structure for lidar scanner, developing Multi-layer PCB that integrate various component such as laser module. Motor etc. A critical aspect of the design is the cylindrical cam mechanism, precisely constructed and optimized using advanced simulation tools to ensure accurate and consistent scanning.

This project highlights a comprehensive approach to developing a cost-effective, high-performance 3D LiDAR scanner designed for applications that require detailed 3D mapping but do not demand the speed of industrial-grade scanners. This project is divided into several parts, each crucial for the success of the final product. In the first part, we analyze existing LiDAR scanners and their limitations, and we identify industrial standards. Before we actually jump into design, we thoroughly analyze requirements, needs, and other important factors. After proper planning, we proceed to design our product.

This report explains the main parts of the 3D LiDAR scanner, for example, the laser scanner, cam mechanism, and data processing software. What's more, it lists some of the advantages of introducing these systems, among others that could be high-resolution mapping, cost savings, and the adaptability of being used in multiple settings. Concrete aspects that are such as system design, implementation problems, and cost analysis are also given. The comprehensive report that covers the systems' thinking is for the organizations and scholars looking to exploit the advantages of the 3D mapping with LiDAR technology by saving the budget

2. Review Progress

Extensive research in 3D mapping technology related to Lidar sensors was conducted in order to evaluate available systems and technologies. Manufacturer designs were compared from different sources that included academic publications, conference papers, and specification sheets about Lidar units, and the readings were used to differentiate between the advantages and disadvantages of Lidar technology in 3D mapping

Lidar manufacturers like Velodyne, Ouster, and Quanergy were established as the best fits for the requirements based on a detailed assessing of the product features, the system's performance, and the pricing ratio. The requirement of the Lidar systems that would meet the project's specifications was ensured through, among other things, analysis of various aspects such as the range, resolution, field of view, and adaptability to different climatic conditions.

in this part we analysis the various industrial lidar scanners and identified their limitations as well as their intended working areas. We analyzed their mechanical structures, how they use laser modules, etc. Each lidar scanner is designed to be employed in specific area. Velodyne lidars are mainly used for automotive applications due to their fast data processing technique. RP lidars are used map 2d point cloud. They are used in robot navigation. Some lidar scanners are used for high resolution mapping purposes, filming industry. Revopoint pop3 is high resolution static lidar scanner which use for those purposes.

2.1) Existing Products in the Market

- **Velodyne Lidar**

- 16 Channels
- Measurement Range: 100 m
- Range Accuracy: Up to ±3 cm (Typical)1
- Field of View (Vertical): +15.0° to -15.0° (30°)
- Angular Resolution (Vertical): 2.0°
- Field of View (Horizontal): 360°
- Angular Resolution (Horizontal/Azimuth): 0.1° – 0.4°
- Rotation Rate: 5 Hz – 20 Hz
- Integrated Web Server for Easy Monitoring and Configuration
- Power Consumption: 8 W (Typical)

Figure 1: Velodyne

- **Hokuyo UTM-30LX**

➢ Detectable range 0.1 m – 30 m
➢ Scanning angle 270°
➢ Angular resolution 0.25°
➢ Power Consumption

Figure 2: Hokuyo UTM-30LX

- **RP-Lidar**

➢ Operating Range White object: 12 meters Black object: 10 meters Minimum Operating ranging 0.2m
➢ Sample Rate 16 kHz
➢ Scan Rate Typical value: 10 Hz (adjustable between 5 Hz-15 Hz) Angular Resolution 0.225°
➢ Scan Field Flatness ±1.5.
➢ Communication Interface TTL UART
➢ Communication Speed 256000 bps

Figure 3: RP-Lidar

- **Revopoint POP3**

➢ Up to 0.1mm accuracy
➢ Up to 18fps smooth scanning
➢ Up to 0.05mm fused point distance
➢ Scan Field Flatness ±1.5.
➢ Smart stabilization

Figure 4: Revopoint POP3

- **SICK Lidar Scanner**

➢ Up to 100 meters (328 feet) for detecting objects.
➢ Up to 0.2° angular resolution for both horizontal and vertical fields of view
➢ Adjustable depending on the specific model and configuration
➢ Up to 200 Hz for scanning with configurable settings to balance between scan resolution and speed.

Figure 5: SICK

2.2) Industrial applications

Autonomous vehicles

LiDAR technology is crucial for autonomous vehicles, providing high-resolution 3D maps that enable precise navigation and obstacle detection. The sensors help self-driving cars to detect lane markings, other vehicles, and potential hazards, ensuring safe and efficient operation. This real-time data is essential for the vehicle's control systems to make informed decisions and avoid collisions.

Figure 6

Geospatial and Surveying

LiDAR is extensively used in geospatial and surveying applications to create accurate topographic maps and 3D models. This technology is vital for urban planning, construction, and environmental monitoring. In forestry, LiDAR measures canopy height and biomass, aiding in forest management and conservation efforts. Its ability to capture detailed terrain data makes it an indispensable tool for surveyors.

Figure 7

Construction and Architecture

In construction and architecture, LiDAR contributes to Building Information Modeling (BIM) by providing precise 3D models of buildings and construction sites. This enhances design accuracy and project management. LiDAR's detailed site surveys ensure structures are built according to specifications, improving overall project efficiency and reducing errors.

Figure 8

Agriculture

LiDAR plays a significant role in precision agriculture, helping farmers optimize irrigation, monitor crop health, and manage soil properties. By creating detailed maps of agricultural fields, LiDAR enables better decision-making and resource management. It also assists in analyzing plant height and canopy structure, identifying stress factors that affect crop yield.

Figure 9

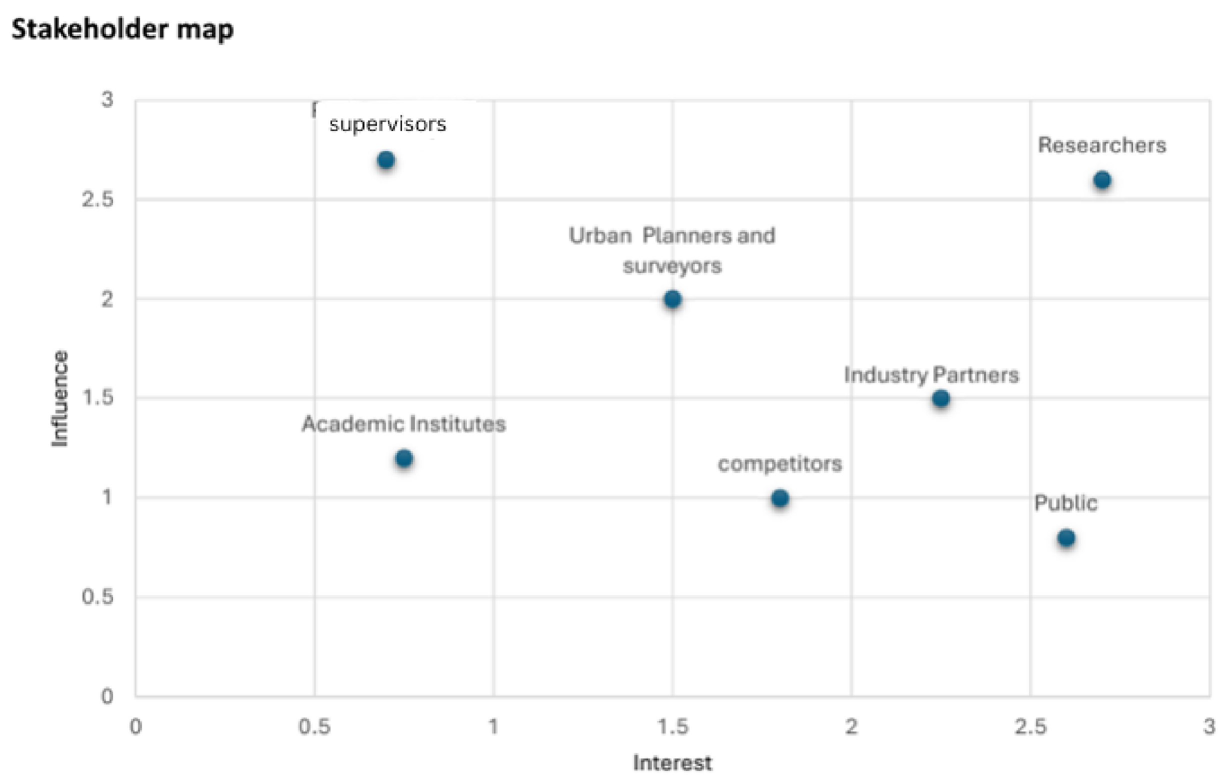
Environmental monitoring

LiDAR is essential for environmental monitoring, such as tracking coastal erosion and managing shoreline changes. It helps create accurate floodplain maps and predict flood behavior, which is critical for disaster preparedness and response. LiDAR's ability to monitor environmental changes supports conservation and resource management efforts.

LiDAR technology has modernized a number of industries by providing accurate spatial data at high resolution. Starting from ensuring autonomous vehicle safety and efficiency to precision agriculture and construction, LiDAR applications are diverse and powerful. Its role in environmental monitoring and resource management proves the significance of LiDAR when it comes to dealing with contemporary threats. With LiDAR technology constantly being upgraded, there is no doubt that this technology would further be used in every sort of industrial process, allowing innovation and increasing functionality from many sectors.

3. Identification of stackholders

Major stakeholders include project team members, supervisors, end-users that involves researchers, urban planners, and surveyors, and industry partners like construction companies and environmental agencies, regulatory authorities, public, academic institutions, and our competitors. All of these stakeholder groups have particular interests and expectations about the project; they also make different contributions towards it. Students want to find cost-effective 3D Lidar solutions, while companies are interested in high accuracy fast lidar scanners. Interest of supervisors and academic institutions is targeted at the educational value of the project and the possibilities it offers for research. Industry partners are interested in the practical results that will improve their operations. Regulatory authorities and the general public show interest in terms of compliance and the implications for society. The mere presence of competitors pushes innovation and quality standards. The next step would be to recognize and then rank stakeholders in terms of influence and involvement; the end-users and industry partners will obviously come to the front because of direct application and feedback. Supervisors and academicians are also critical in ensuring accuracy and relevance in a project. All of these interests strike a careful balance for a versatile, effective 3D Lidar solution to emerge.



4. Observe Users

In terms of observation of user interaction with LiDAR technology, and crucially to inform different stakeholder needs, we would conduct user observation sessions that would be important in gaining an in-depth understanding of the many ways in which our different stakeholders use our product, their specific preferences, and potential fault points. Usability evaluations and feedback sessions for capturing comprehensive knowledge of the behavior of users in different situations will be carried out through field testing and usability studies.

Key Objectives:

1. **Understanding User Behaviors and Preferences:** By closely observing users in action, we seek to uncover nuanced behaviors and preferences that influence their interactions with our LiDAR technology. This includes how they integrate it into their workflows and the specific functionalities they prioritize.
2. **Identifying Usability Challenges:** Through systematic observation, we will pinpoint any usability issues, inefficiencies, or barriers that users encounter. This insight is crucial for refining the design to enhance user experience and operational efficiency.
3. **Validating Design Assumptions:** User observation will validate our initial design assumptions and hypotheses. By witnessing firsthand how users engage with the technology, we can confirm or adjust our design decisions to better align with user needs and expectations.
4. **Iterative Design Improvement:** Feedback gathered from users will drive iterative design improvements. Documenting and analyzing user input enables us to iteratively refine the product, ensuring it evolves in a direction that maximizes user satisfaction and utility.

In order to handle user satisfaction we are aiming to develop software for this 3d lidar scanner that can guide user to use this product correctly. This software aims to handle different interfaces like USB, UART and is used to visualize 3d point clouds.

Overall, these user observation sessions are very important to this design process.it enabling us to create a 3D LiDAR scanner that not only meets but exceeds user expectations through informed and user-centered design decisions. By actively engaging with stakeholders and incorporating their feedback, we ensure the final product is robust, intuitive, and optimally aligned with real-world user requirements.

5. Need List

1. **Accuracy of Measurements:**

    High accuracy is essential for applications requiring detailed 3D surface mapping, such as urban planning, construction site monitoring, and archaeological surveys. Precise measurements ensure that digital representations faithfully reflect real-world conditions. However, for applications like mapping for moving vehicles (e.g., autonomous cars), a degree of accuracy sufficient for navigation and obstacle detection may be prioritized over ultra-high precision.

2. **Speed of Data Acquisition:**

    The speed at which LiDAR scanners acquire and process data is critical, especially in dynamic environments or for fast-moving vehicles. Rapid data acquisition enables real-time mapping and quick updates of environmental changes, enhancing the efficiency and effectiveness of applications such as autonomous driving and dynamic object tracking.

3. **Range of Operation:**

    The operational range defines how far the LiDAR scanner can effectively detect and measure objects. A wide range capability ensures versatility in different environments, from short-range indoor applications to long-range outdoor scanning required in aerial surveys or large-scale infrastructure projects.

4. **Environmental Adaptability:**

    LiDAR scanners must operate reliably in various environmental conditions, including bright sunlight, rain, fog, and dusty or low-light environments. Robust environmental adaptability ensures consistent performance across diverse scenarios without compromising data quality or accuracy.

5. **Cost-Effectiveness:**

    Achieving a balance between performance and cost is crucial for widespread adoption. Cost-effective solutions make LiDAR technology more accessible across industries, promoting its integration into mainstream applications like smart city initiatives, precision agriculture, and industrial automation.

6. **Compatibility with Existing Systems:**

    Seamless integration with existing hardware and software ecosystems simplifies deployment and enhances interoperability. Compatibility ensures that LiDAR scanners can easily interface with other sensors, processing platforms, and communication networks, facilitating comprehensive data fusion and analysis.

7. **Reliability and Durability:**

Reliable operation and durability are paramount, particularly in demanding environments and prolonged use cases. Robust construction and adherence to stringent quality standards minimize downtime and maintenance costs while ensuring consistent performance over extended periods.

8. **Power Consumption:**

   Efficient power management is essential for mobile applications and remote deployments where energy resources may be limited. Low power consumption prolongs operational uptime and reduces overall operational costs, making LiDAR scanners more sustainable and practical for continuous use.

9. **Ease of Use:**

   Intuitive interfaces, straightforward calibration procedures, and user-friendly software enhance operational efficiency and user adoption. Simplified setup, configuration, and data visualization tools empower operators to maximize the capabilities of LiDAR technology with minimal training or technical expertise.

10. **Data Processing Efficiency:**

    Optimized data processing capabilities streamline the extraction of actionable insights from raw LiDAR data. Advanced algorithms for point cloud processing, object recognition, and spatial analysis accelerate decision-making processes in applications ranging from urban planning to disaster response.

11. **Scalability:**

    Scalable solutions accommodate varying project scopes and evolving operational requirements. Modular designs and flexible configurations enable LiDAR systems to scale from single-unit deployments to networked arrays or integrated platforms supporting complex, multi-sensor architectures.

12. **Support and Maintenance:**

    Comprehensive support services, including technical assistance, software updates, and timely maintenance, ensure continuous functionality and performance optimization. Responsive customer support and readily available spare parts minimize downtime and maximize operational uptime.

13. **Portability and Mobility:**

    Compact, lightweight designs enhance portability for mobile applications, such as airborne surveys or handheld scanning tasks. Easy transportability and rapid deployment capabilities enable LiDAR scanners to access remote or challenging locations, expanding their utility across diverse industries.

In summary, developing a robust 3D LiDAR scanner involves addressing a wide range of technical requirements and user needs. By prioritizing high accuracy, speed, environmental adaptability, cost-effectiveness, and ease of use, manufacturers can deliver solutions that empower users across industries to leverage the full potential of LiDAR technology in diverse and demanding applications

6. Stimulate Ideas

1. **Affordable Precision with Single Laser Module:**
   - **Idea:** Develop a 3D LiDAR scanner using a single laser module to achieve high precision in 3D mapping while maintaining affordability.
   - **Inspiration:** This approach addresses market demand for cost-effective solutions without compromising on the accuracy required for detailed 3D surface mapping in various applications.

2. **Mechanical System for Reliable 3D Mapping:**
   - **Idea:** Implement a robust mechanical system to ensure reliable and precise 3D mapping in diverse environmental conditions.
   - **Inspiration:** Most 3d lidar scanners use simple mechanical systems because they use high number of laser modules. But this 3d lidar scanner product 3d visibility is achieved from robust mechanical system. Enhance stability during data capture, minimizing errors and optimizing performance, crucial for industries such as construction and autonomous navigation.

3. **Comprehensive Software Integration:**
   - **Idea:** Develop integrated software to simplify data mapping, configuration, and analysis processes for the LiDAR scanner.
   - **Inspiration:** Empower users with customizable scanning parameters and efficient data processing capabilities, enhancing usability and supporting continuous technological advancements.

4. **User-Centered Design for Ease of Use:**

- **Idea:** Design a user-centered interface for intuitive operation and enhanced workflow productivity.
- **Inspiration:** Prioritize accessibility and functionality to reduce the learning curve, making the LiDAR scanner suitable for both field surveys and automated systems integration.

5. **Scalable and Future-Ready Architecture:**
    - **Idea:** Create a modular and upgradeable architecture to accommodate future enhancements and technological advancements.
    - **Inspiration:** Ensure compatibility with evolving LiDAR technologies and project requirements, offering long-term value and reliability across diverse industries.

6. **Reliability and Durability in Challenging Environments:**
    - **Idea:** Engineer the LiDAR scanner for durability and consistent performance in demanding indoor and outdoor environments.
    - **Inspiration:** Utilize high-quality materials and stringent quality standards to minimize maintenance costs and downtime, ensuring dependable operation over extended periods.

These ideas and their inspirations underscore the innovative approach and unique features of our 3D LiDAR scanner, demonstrating its capability to meet stringent industry demands while advancing technological capabilities in 3D mapping solutions.

7. Develop Concept

Brainstorm potential ideas and solutions to address the identified needs and requirements. Encourage creativity and innovation by exploring different approaches and considering alternative technologies or methodologies. Engage stakeholders in idea generation workshops or collaborative discussions to generate diverse perspectives and insights.

For this design we came up with three conceptual designs. These conceptual designs have its own advantages and disadvantages.

7.1 Conceptual Design 1

We have used two stepper motors, and TFMini-S LIDAR sensor to collect the coordinates of the 3D space to plot the point cloud. This design doesn't allow us to have a continuous rotation. TFMini-S can measure long distances but slow data rates. Due to noncontinuous rotation jerks may occur. In this design we use stepper motor and servo motor. Because of that high precision is needed when calculating 3d coordinates. Compared to other designs this design has fewer 3d parts. Compared to other designs this design is much simpler

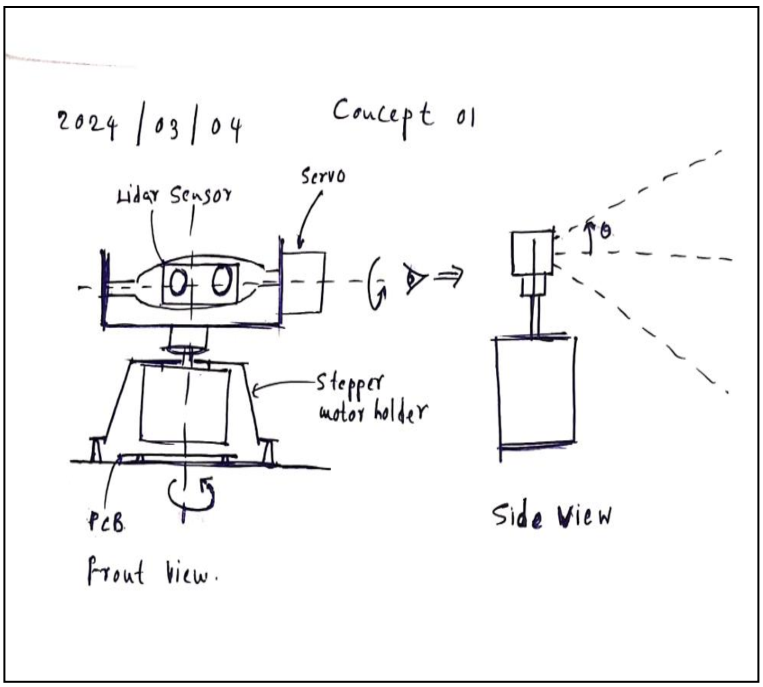


Figure 10: conceptual design 1

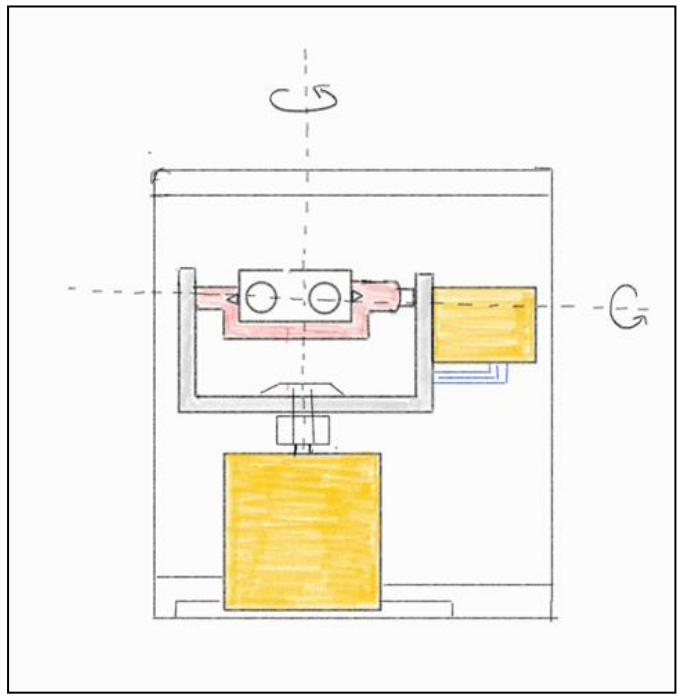


Figure 11: conceptual design 1

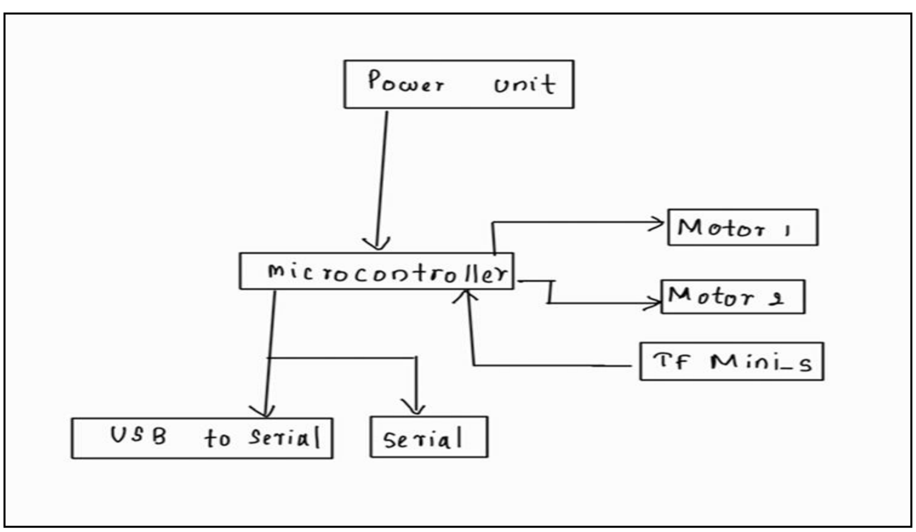


Figure 12: Block Diagram of design 1

7.2 Conceptual Design 2

This design consists of mirror to achieve reflecting properties in contrast to previous conceptual designs. The main advantage is this structure can achieve both continuous rotation and long-range coordinates at the same time, therefore this conceptual design is a hybrid of the previous two. In this design mirror angle is a important factor. 3d coordinates can change significantly from small error of angle of mirror. Same as the previous design this design also uses two motors. 3d structure is little bit complex compared to previous one. One advantage of this module is that the laser module is static. This increases the durability of the laser module and wiring of the system is much simpler.

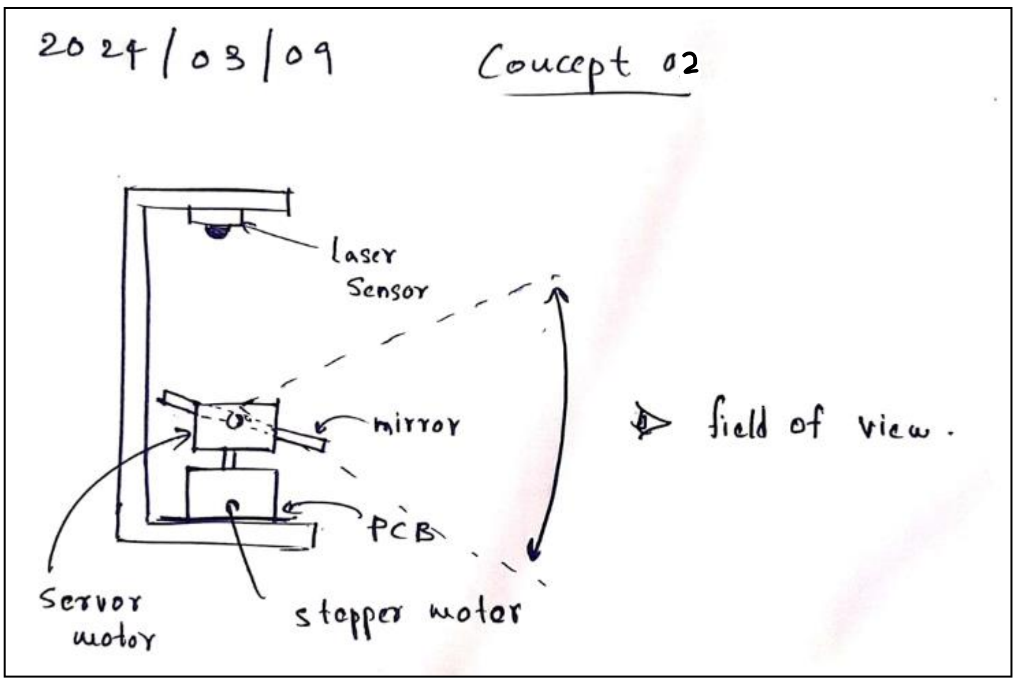


Figure 13: conceptual design 2

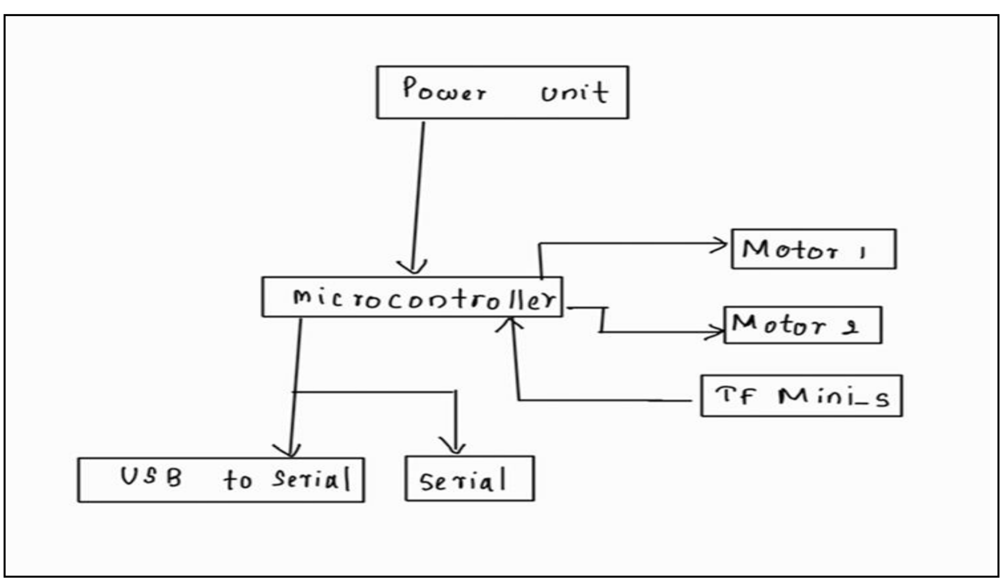


Figure 14: Block Diagram of design 2

7.3 Conceptual Design 3

We selected Conceptual Design 3 for its continuous rotation feature, providing high accuracy essential for precise mapping. Its moderate speed suits selected applications, while its lower cost compared to alternatives makes it economically feasible. Additionally, Conceptual Design 3 offers enhanced reliability, ensuring consistent performance in demanding conditions. Most importantly this design needs only one motor. This reduces the cost of the design and calculation is much simpler compared to other designs. In this design a sufficiently complex mechanical system is used to achieve horizontal rotation with vertical rotation. When base motor is rotating, laser module is rotated with it and also it rotate in vertical direction. Compared to other designs this design needs robust and complex 3d structure and also this design needs high precision materials and components.

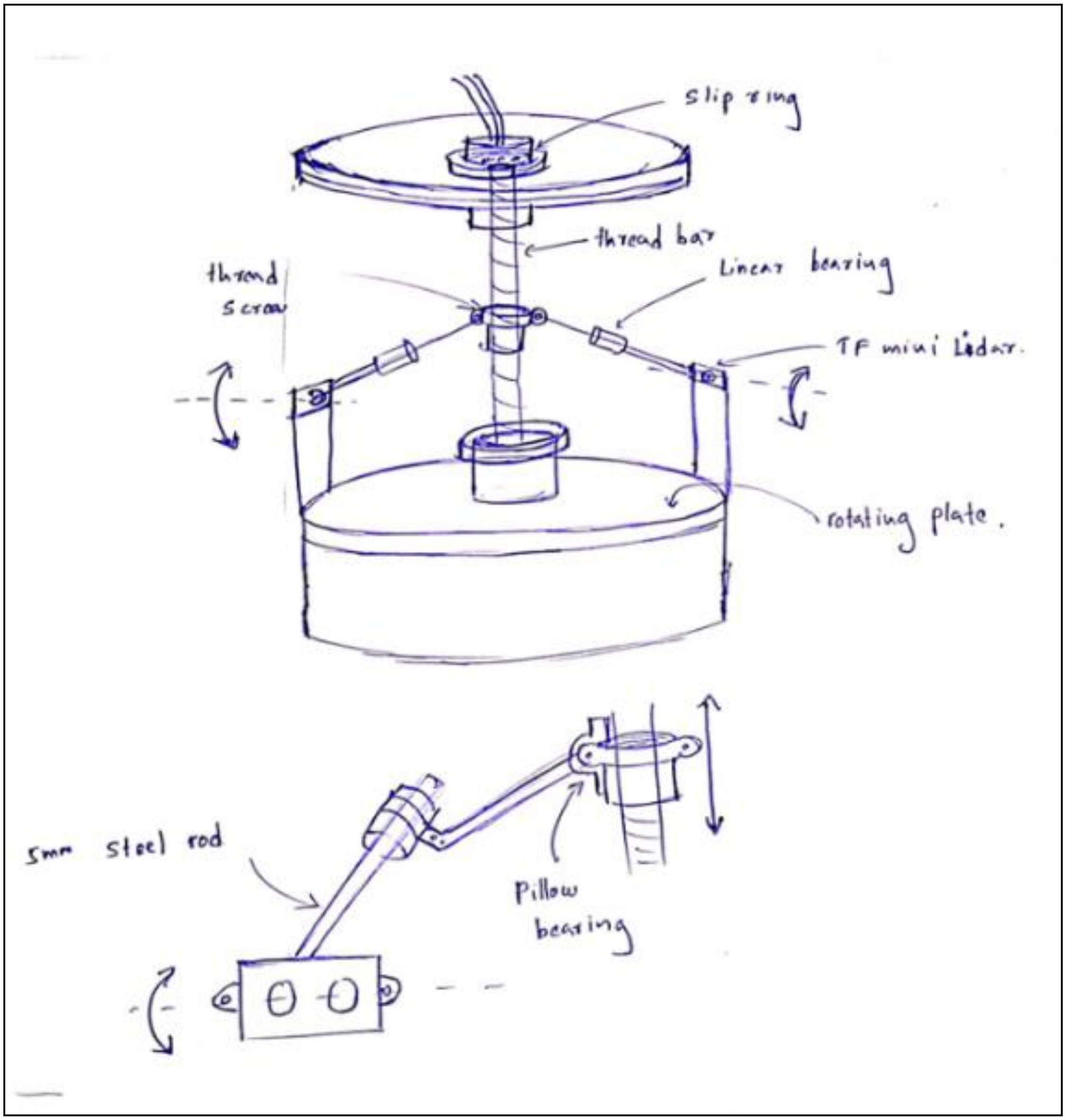


Figure 15: conceptual design 3

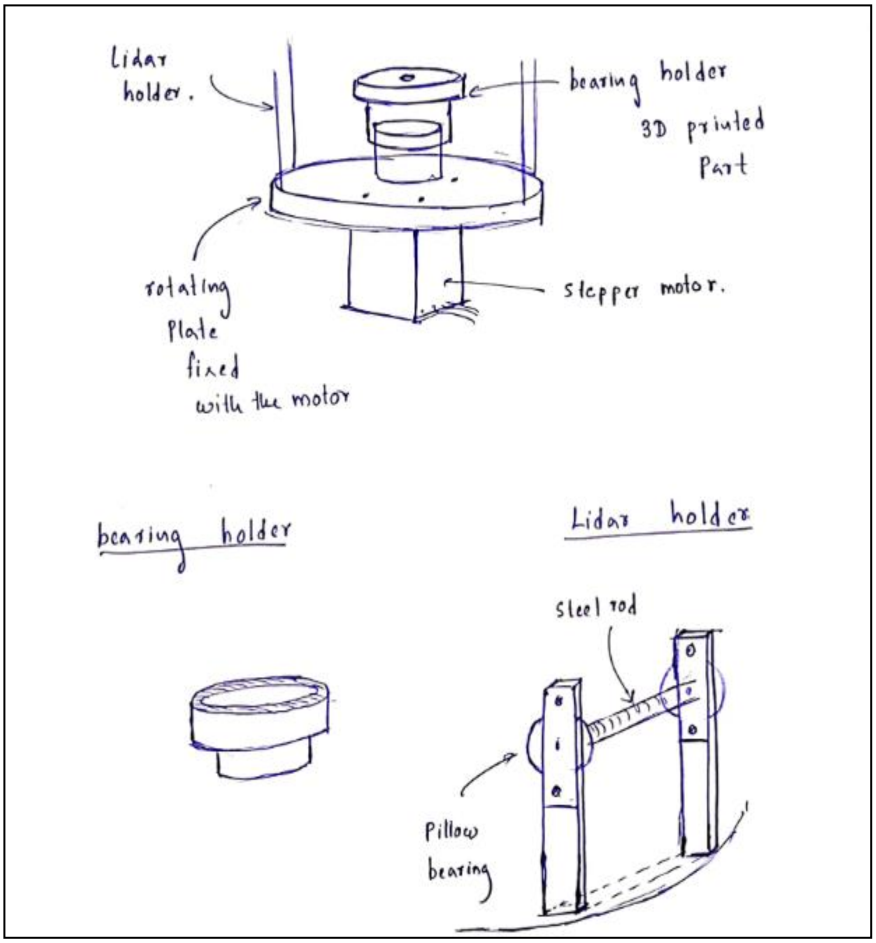


Figure 16: mechanical parts

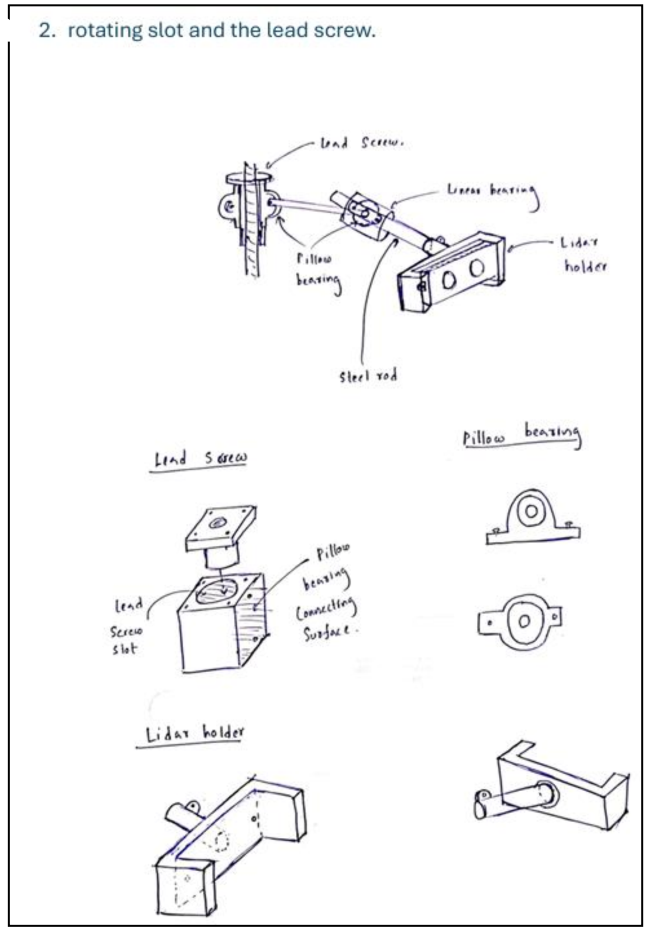


Figure 17: mechanical parts

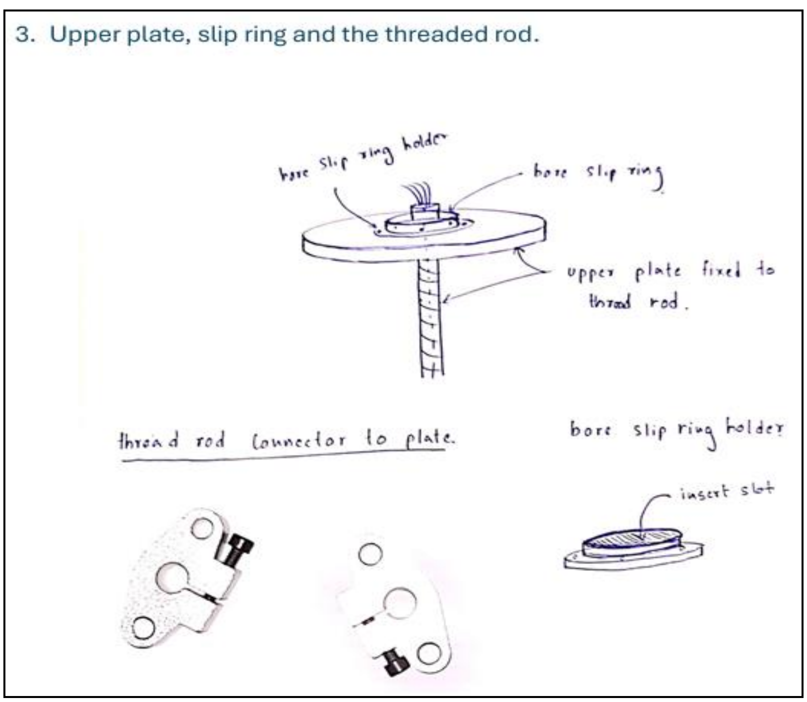


Figure 18: mechanical parts

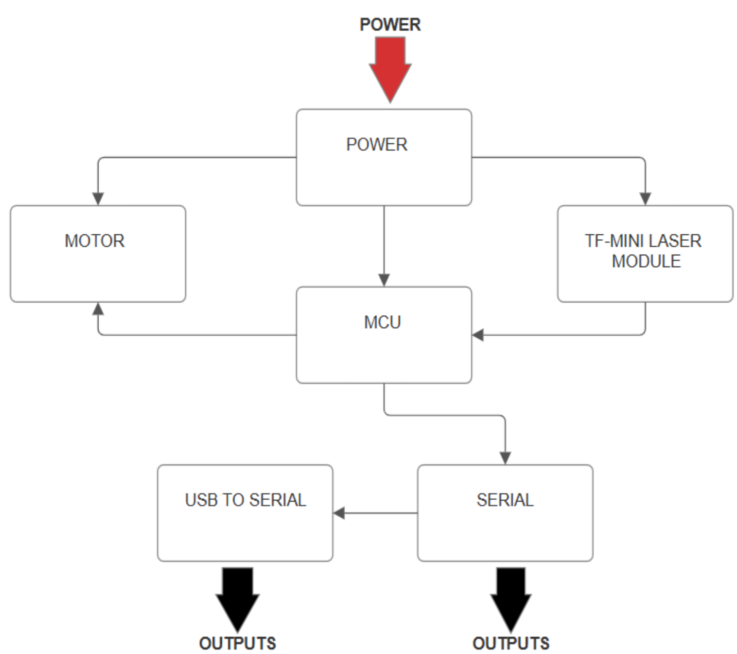


Figure 19: Block diagram of design 3

8. Evaluation of Conceptual Design

Functional design criteria comparison

	Conceptual Design 1	Conceptual Design 2	Conceptual Design 3
Scan Rate and Data Output:	6	9	8
Accuracy and precision	7	5	9
Size, Weight, and Power Consumption (SWaP)	7	7	9
Cost and Scalability	9	5	8
Simplification of calculations and design complexity	9	6	8
Total	**38**	**32**	**42**

Enclosure design criteria comparison

	Conceptual Design 1	Conceptual Design 2	Conceptual Design 3
Functionality	5	7	9
Simplicity	9	7	5
Durability	5	7	9
Heat dissipation	5	7	8
Ergonomics	9	6	8
Total	**33**	**34**	**39**

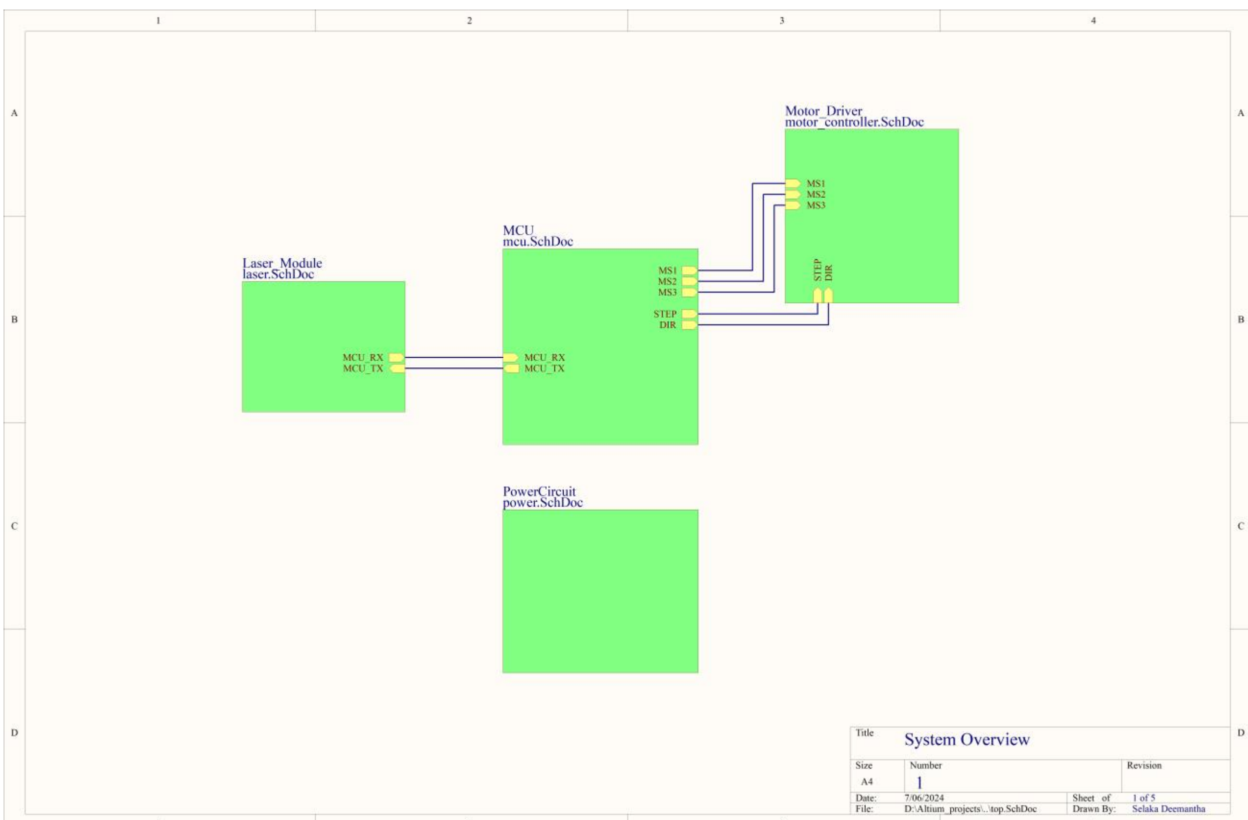
9. Dicision Rational

The third conceptual design was chosen for the 3D LiDAR Scanner since it efficiently uses just one motor, greatly simplifying the system. This approach reduces not only mechanical complexity and increases reliability but also provides easy maintenance. Besides, high data rates are ensured, which results in rapid and accurate data acquisition.

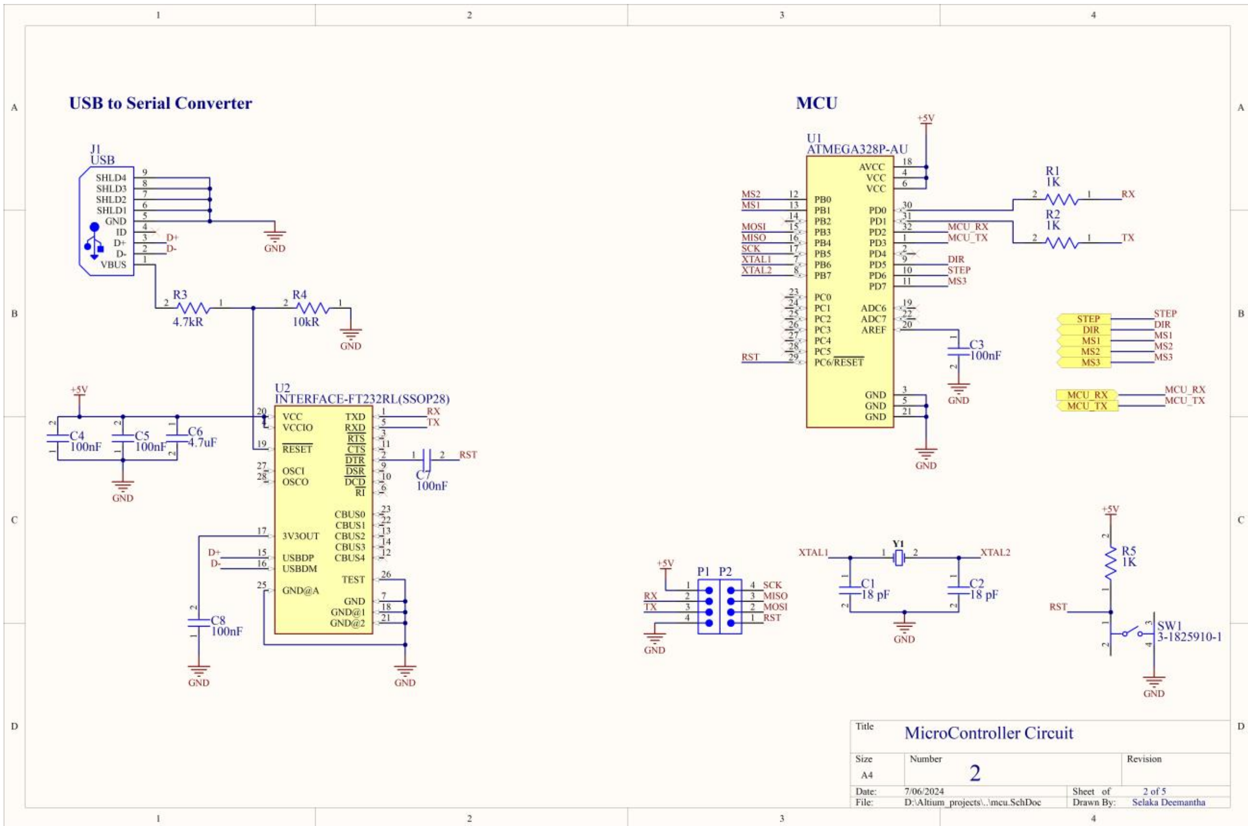
This means that with one motor, the design reduces the number of points of failure and operational complications that could otherwise exist in the scanner, resulting in a stronger and more long-lasting device. This simple nature attends to faster development and easier troubleshooting, a factor that also ensures continuous performance. This choice underlines the preference for practical efficiency and a high data throughput, making it ideal for applications requiring rapid, accurate 3D scanning. The third design mitigates well to meet the viewpoints regarding high-performance scanning criteria from the project while keeping a simple and reliable system architecture.

10. Schematic Design

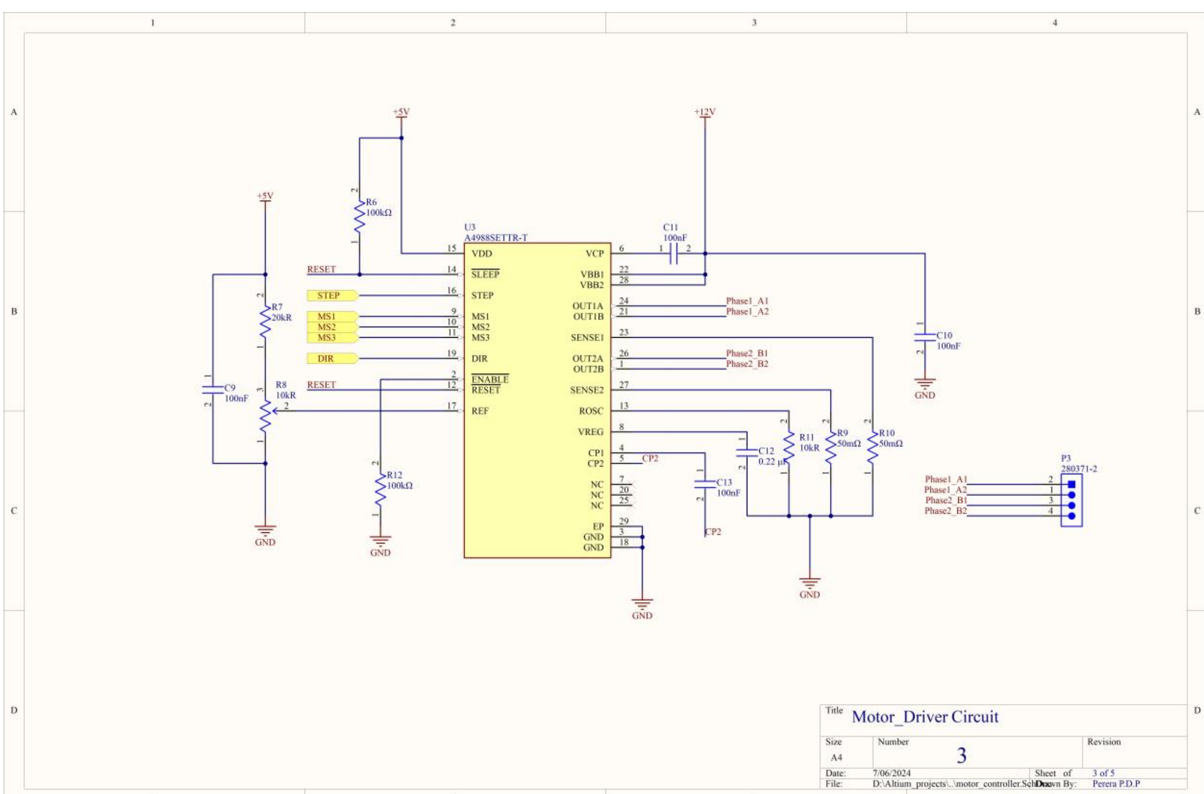
- **System Overview**



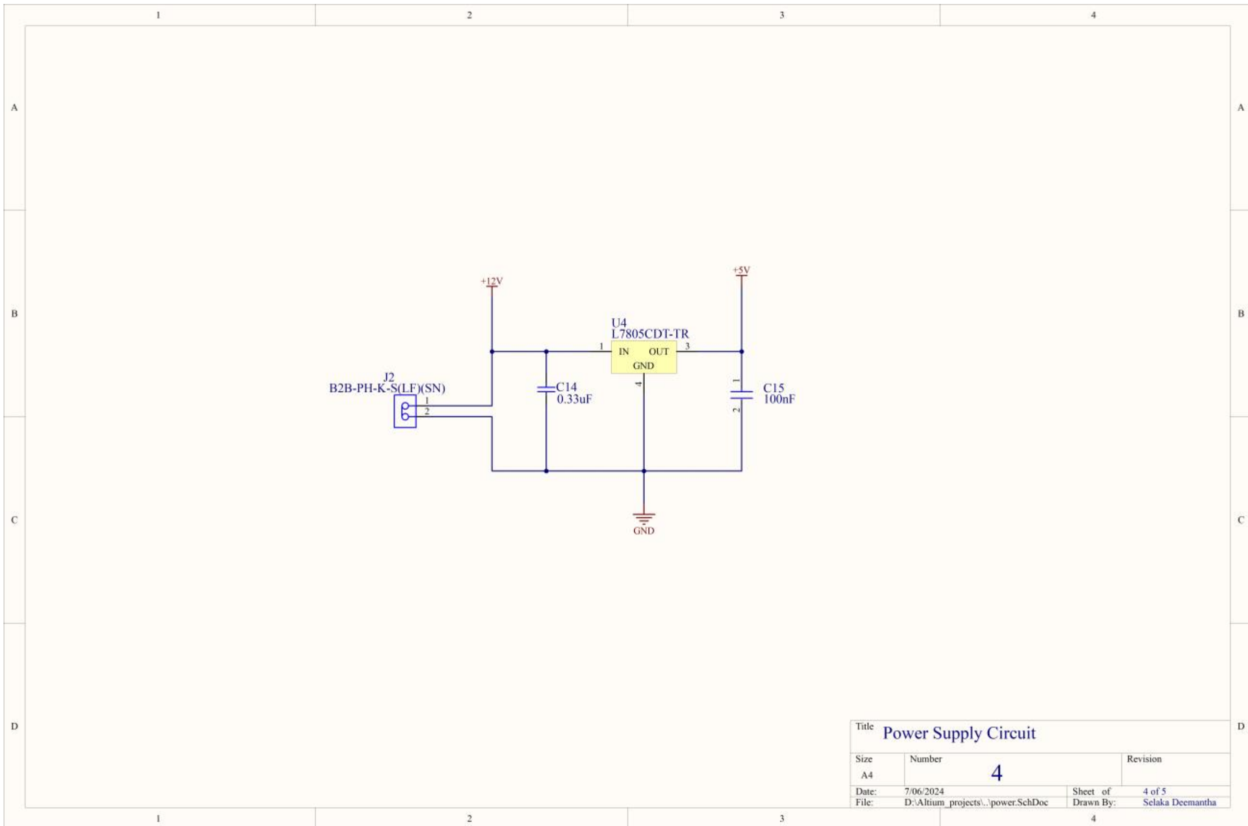
- **MCU with USB to Serial Converter**



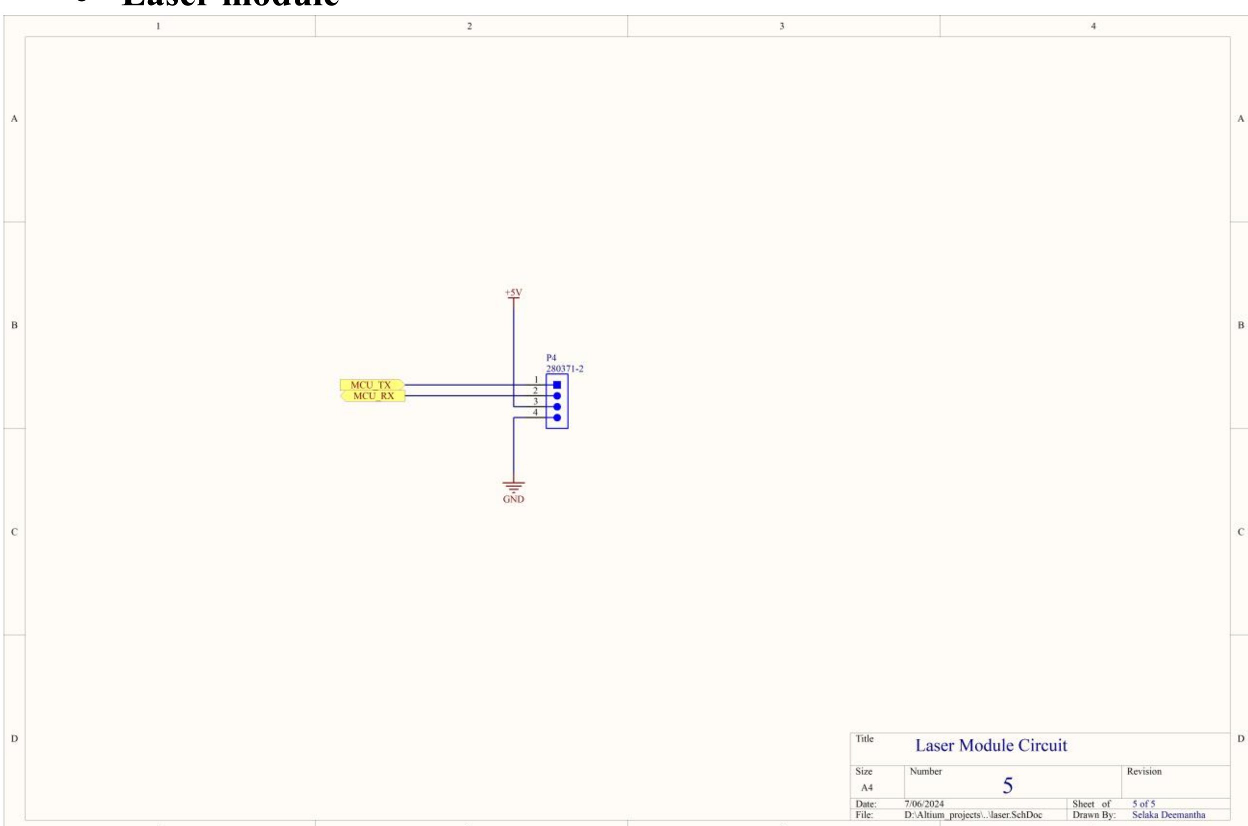
- **Motor controller**



- **Power supply**



- **Laser module**



11. PCB Design

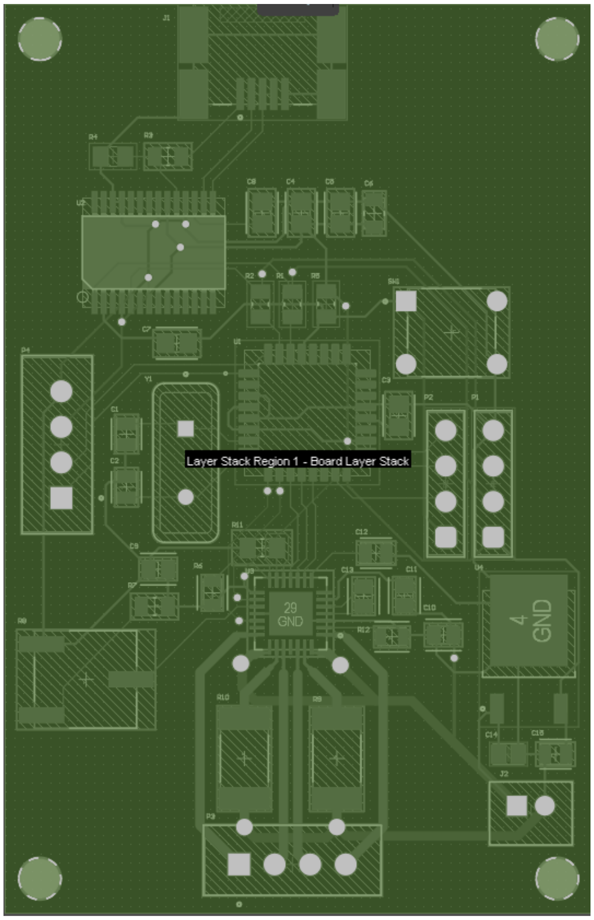


Figure 25: Board planning view

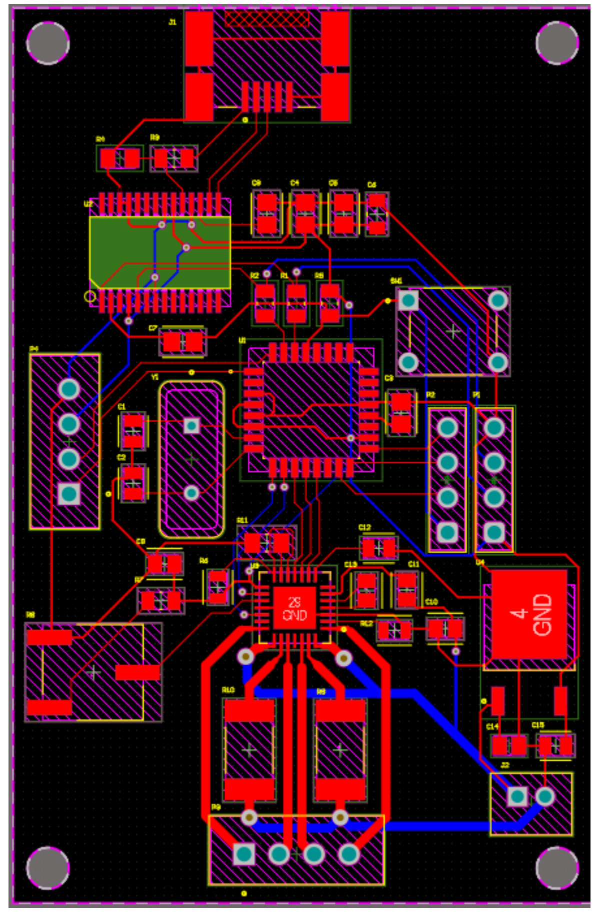


Figure 26: 2D view

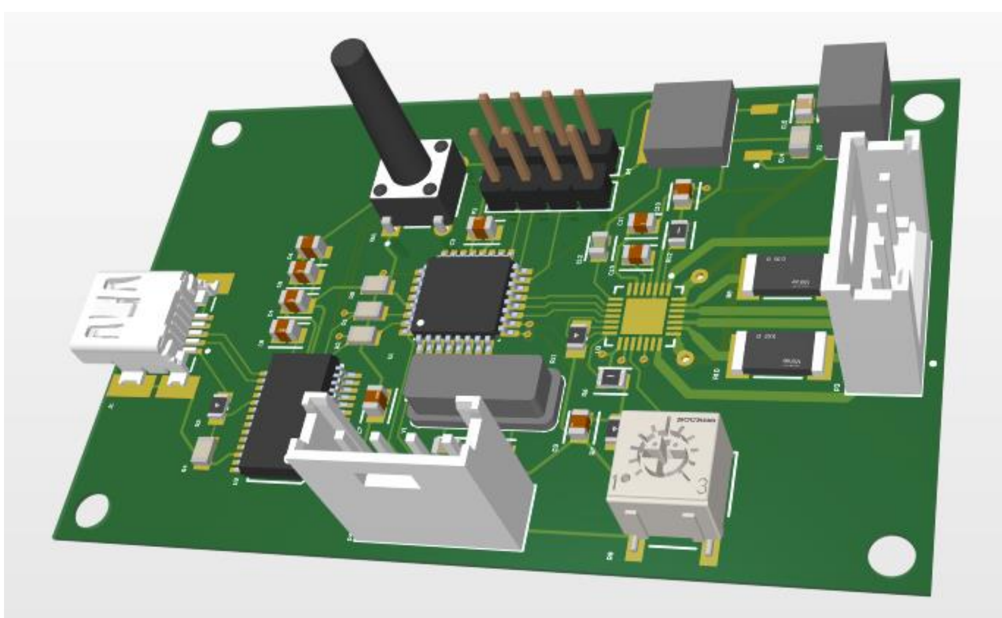
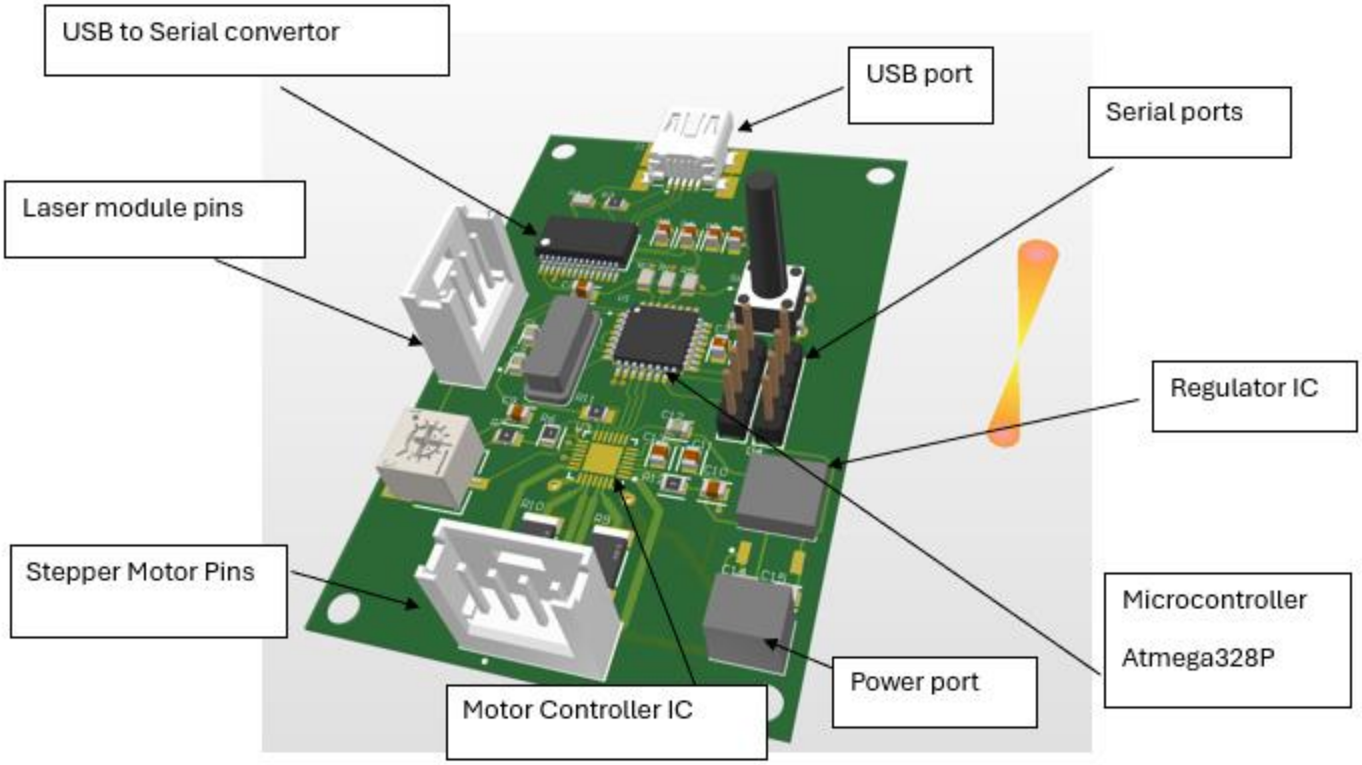


Figure 27: 3D view

3D view of the PCB



Dimensions

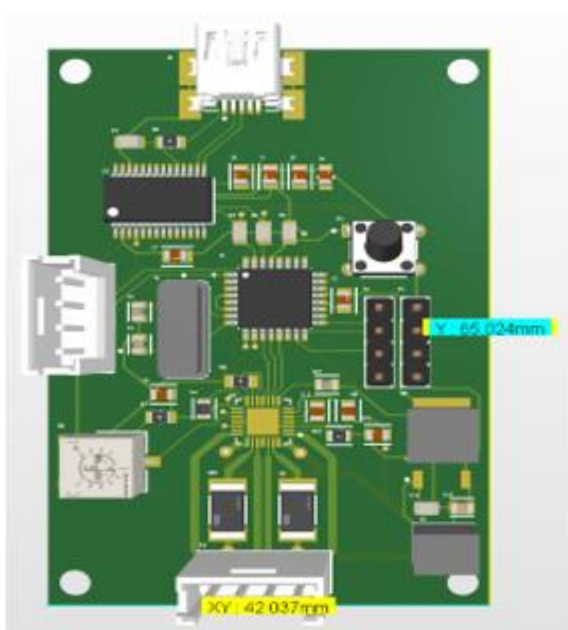


Figure 28: PCB Dimensions

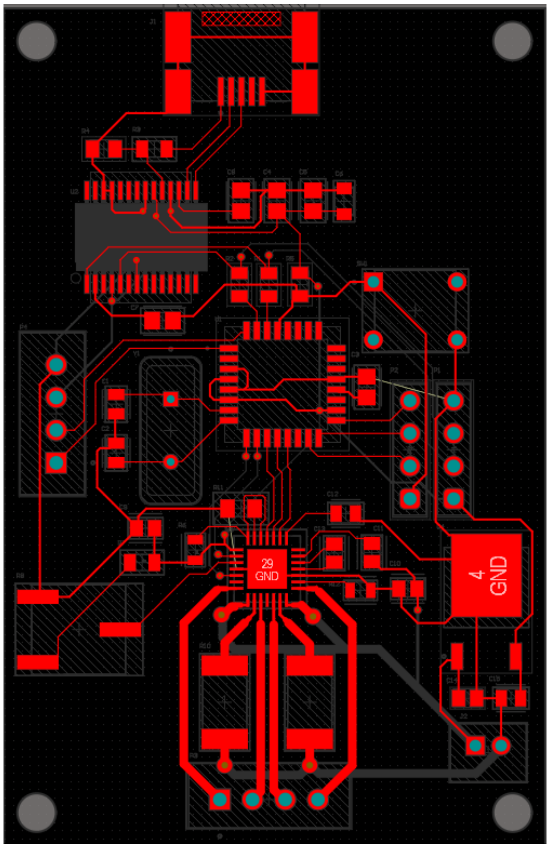


Figure 29: Top Layer

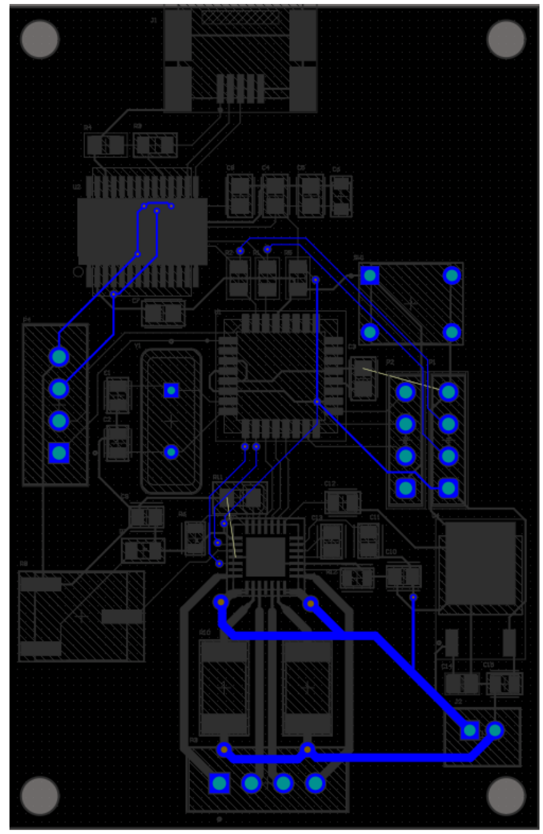


Figure 29: Bottom Layer

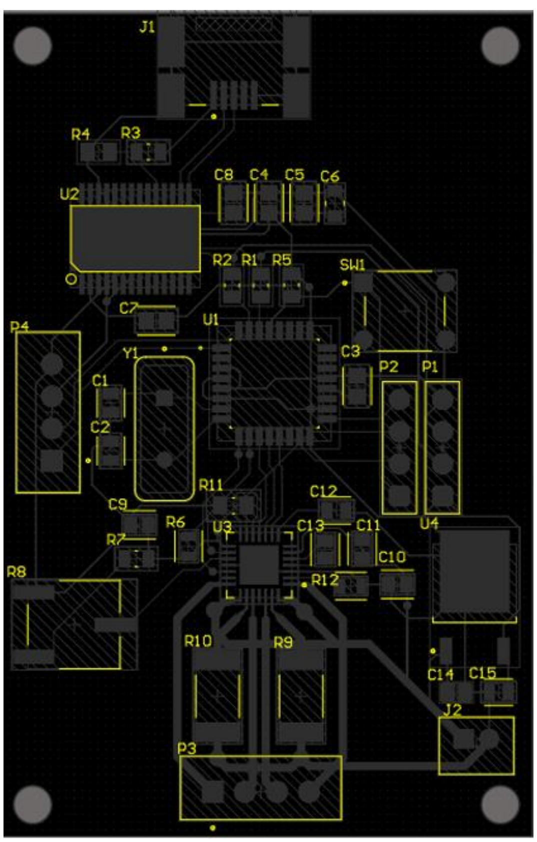
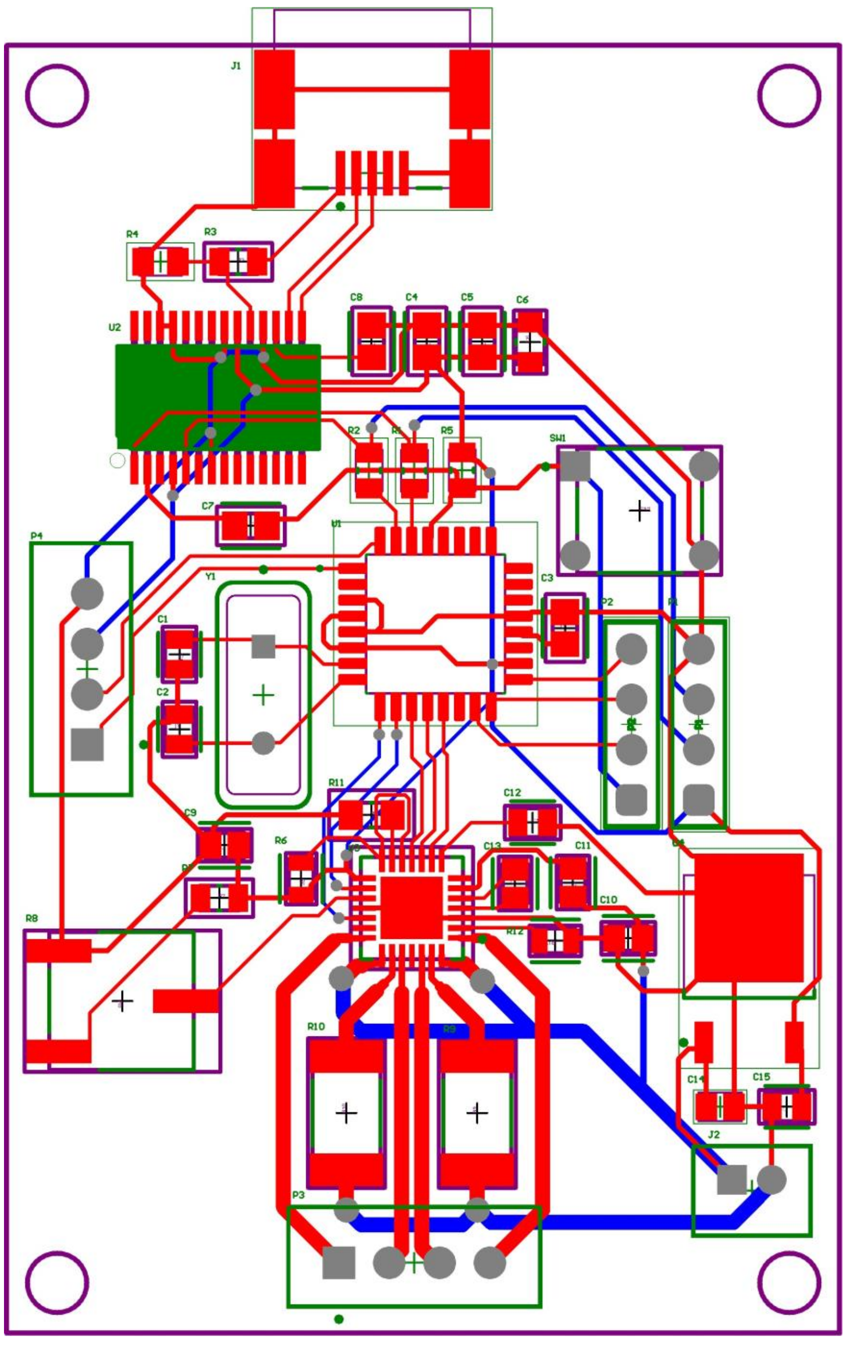


Figure 30: Top Overlay

In our project, we implemented a thoughtful PCB (Printed Circuit Board) design to ensure both performance and reliability for our 3D mapping system. Given the need to support a stepper motor with a 2A current supplied by the motor controller, we had to design wider trace widths and larger via diameters to handle this high current efficiently. Additionally, we took into account the design constraints of JLCPCB, which influenced our design choices.

Our two-layer PCB design required accurate attention to signal routing and power distribution. To minimize noise and prevent interference, we avoided using large copper pours for signal traces. Instead, we routed individual signal traces to maintain isolation and control over the signal paths, thereby reducing the risk of unintended coupling.

We emphasized the strategic placement of decoupling capacitors close to the components they support. This placement ensures that high-frequency noise and transient disturbances are effectively filtered out, which is crucial for maintaining the performance and reliability of the motor control circuits.



12. SolidWorks Design

This design contains mainly two parts, an outer enclosure and mechanical part. We use SolidWorks to design outer enclosure and some parts of the mechanical system

12.1 SolidWorks Designs of Parts

Figure 31: SolidWorks design parts

12.1 SolidWorks Design of Full Design

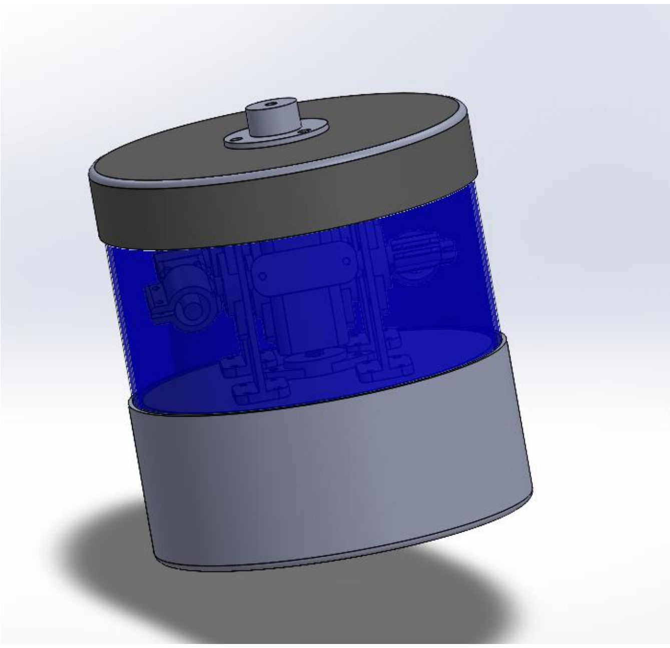


Figure 32: Full Design 1

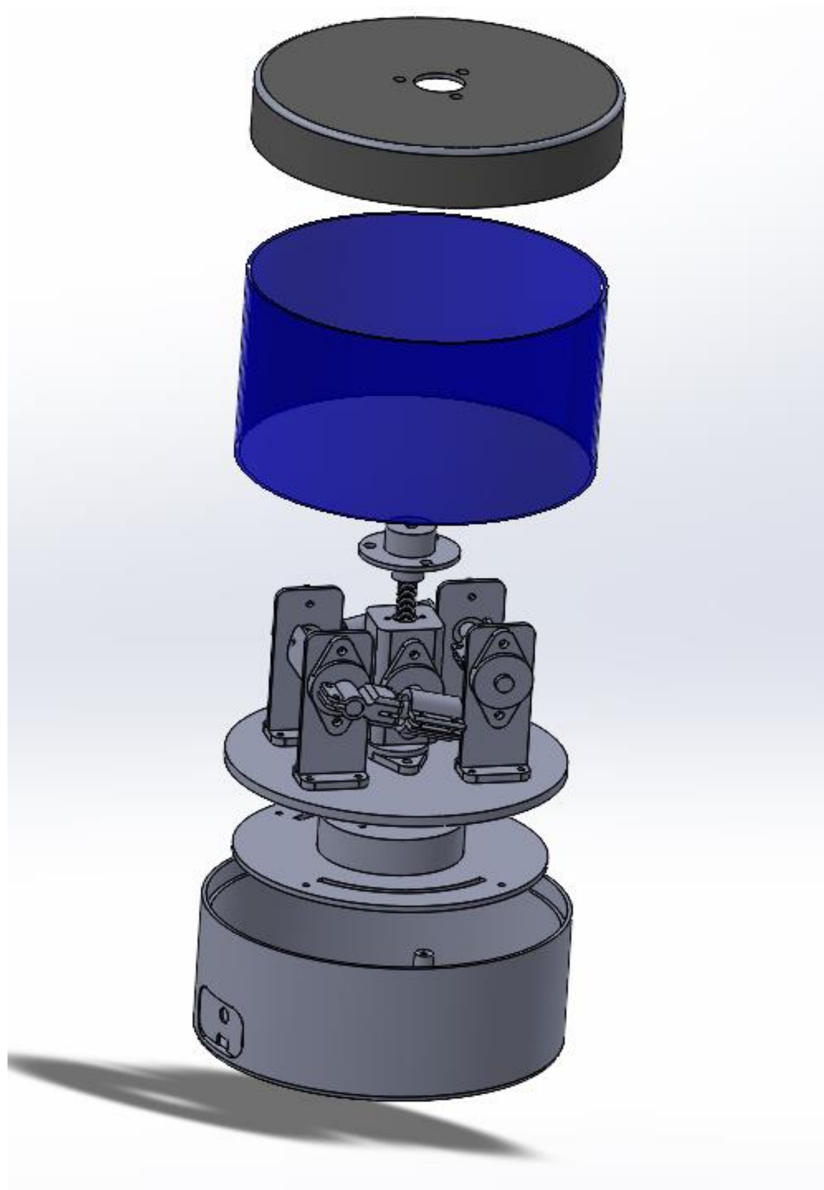


Figure 33: Full Design 2

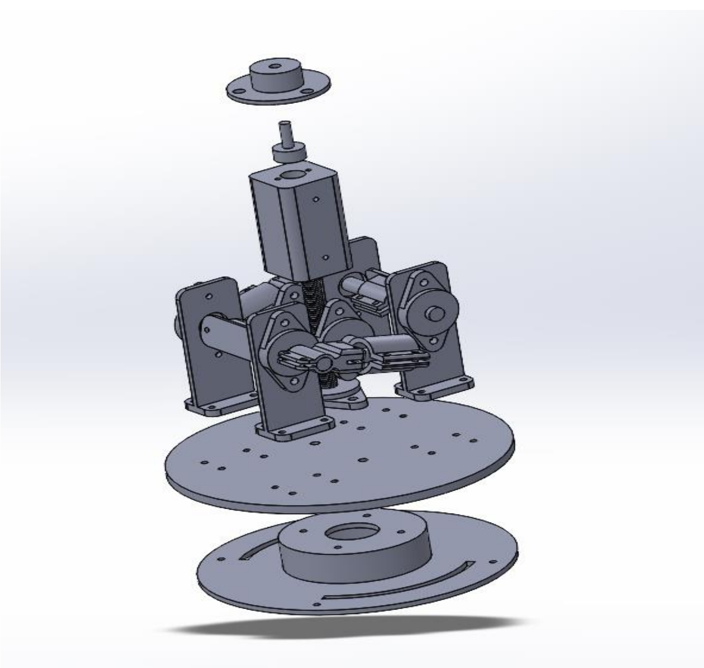


Figure 34: Mechanical Structure

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