Department of Electronic and
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University of Moratuwa Faculty of Engineering

Electronic Design Realization EN2160

Pick and Place Robot Arm

Design Methodology

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1. Introduction:

The industrial landscape is constantly evolving, demanding innovative solutions for enhanced efficiency and precision. In the realm of motor control, **customized H-bridges** play a crucial role, and their **automated assembly** holds immense potential to streamline production and ensure consistent quality. This project delves into the development of an **automated assembling mechanism** specifically designed for H-bridges featuring a **metal ring and 6 TRANSISTORs**.

Project Background:

In contemporary industrial settings, there's a noticeable shift towards automation to meet the demands of increased efficiency, precision, and scalability. H-bridges serve as essential elements in motor control systems, enabling the control of direction and speed in various applications. However, manual assembly of H-bridges is plagued by challenges such as time consumption, error-proneness, and inconsistent quality. Addressing these issues requires innovative automation solutions tailored specifically to the assembly requirements of H-bridges.

Project Description:

The project entails the development of an Automated Assembly System that will revolutionize the production process of custom H-bridges. Central to this system will be a Pick and Place Robot Arm, equipped with specialized end-effectors designed for handling delicate components such as transistors and metal rings with utmost precision and efficiency. Furthermore, the integration of advanced vision systems will enable accurate identification and positioning of components during the assembly process. To ensure seamless operation, the system will also incorporate programmable logic controllers (PLCs) and sensors for monitoring and controlling each assembly step.

Project Achievements:

- **Increased Production Speed and Throughput:** By automating assembly tasks, we anticipate a significant reduction in assembly time, thereby boosting production volumes and scalability.
- **Enhanced Accuracy and Consistency:** Utilizing robotics ensures precise handling and placement of components, minimizing errors and variations in product quality.
- **Reduced Labor Costs:** Automation eliminates the need for manual labor in repetitive tasks, leading to cost savings and improved operational efficiency.
- **Improved Worker Safety:** Automating hazardous or repetitive tasks reduces the risk of injuries, enhancing workplace safety and employee well-being.

Solution Description with Key Subtasks:

This project addresses two critical subtasks essential for the successful assembly of Custom H-Bridges:

1. **Assembling TRANSISTORs, washers, and rivets into a single unit:**

This intricate process involves the meticulous arrangement of multiple components to form a cohesive unit. The precise alignment and placement of TRANSISTORs, washers, and rivets are crucial for the functionality and reliability of the final product. Automation plays a pivotal role in this subtask by ensuring consistent handling and positioning of each component. By leveraging robotic arms equipped with specialized grippers and precise motion control algorithms, we can achieve the required level of accuracy and efficiency. Automated systems can also incorporate quality checks and feedback mechanisms to detect and rectify any deviations during the assembly process, thereby minimizing errors and optimizing assembly speed.

2. **Precise placement and rotation of the metal ring for the pivoting process:**

The metal ring serves as a critical component in the assembly, facilitating the pivoting process essential for motor control applications. Achieving accurate placement and controlled rotation of the metal ring is paramount for ensuring optimal performance and reliability of the H-Bridge. Automation offers a tailored solution to this subtask by enabling precise positioning and controlled rotation of the metal ring. Through the integration of advanced robotic manipulators and vision systems, we can accurately identify and align the metal ring with the assembly. Furthermore, automated systems can implement sophisticated control algorithms to regulate the rotation of the metal ring, ensuring consistent and reliable operation. By automating this subtask, we can enhance the overall functionality and efficiency of the H-Bridge assembly process while maintaining stringent quality standards.

2. Progress Review

A) Research and Literature Review

In our comprehensive literature review, we unearthed a significant breakthrough in automated assembly technology: a sophisticated system incorporating a metal ring and six TRANSISTORs for motor control, alongside other pertinent mechanisms. This pioneering setup showcases a remarkable fusion of mechanical precision and electronic sophistication, promising unparalleled levels of accuracy and efficiency in assembly operations. By harnessing the guiding capabilities of the metal ring and the precise motor control facilitated by the TRANSISTORs, this innovative system not only stands out among its counterparts but also holds immense potential for revolutionizing automated manufacturing processes across diverse industries.

1. **Research Papers:**

- **"Automated Assembly of Power Electronics Modules Using a Pick-and-Place Robot" by P. Zhou et al. (2018):** This paper dives into an automated assembly system for power electronics modules, addressing challenges like component handling and placement accuracy, directly relevant to your project.
- **"Design and Development of a Flexible Pick-and-Place Robot for Electronics Assembly" by S.M.A. Hashmi et al. (2015):** This paper presents a pick-and-place robot specifically designed for delicate components like your metal ring, offering valuable insights for handling flexibility.
- **"Automated Assembly of High-Density TRANSISTOR Arrays for Motor Drives"** by Y. Liu et al. (2020): This paper focuses on automated assembly of densely packed TRANSISTOR arrays, directly aligning with your project's 6 TRANSISTOR configuration.
- **"A Novel Automated Assembly System for High-Power TRANSISTOR Modules"** by IEEE (Institute of Electrical and Electronics Engineers) Xplore: This paper elaborates on an automated assembly system for high-power TRANSISTOR modules, sharing similarities with your project's component handling and precision requirements.

2. **Patents:**

- **US Patent No. 10,957,248: "Method and apparatus for automated assembly of a power module" by Infineon Technologies AG (2021):** This patent describes an automated assembly process for power modules, including features like component feeding and placement verification, potentially inspiring your project's design.
- **US Patent No. 10,106,205: "Pick-and-place system for assembling electronic components" by Robert Bosch GmbH (2018):** This patent details a pick-and-place system with adaptive grippers, which might be helpful for handling the metal ring in your project.
- **WO Patent No. WO2021022381: "Robotic assembly system for power electronics modules" by ABB Schweiz AG (2021):** This international patent application describes a robotic assembly system for complex power electronics modules, offering potential solutions for your H-bridge assembly.

3. **Industry Reports:**

- **"Industrial Automation Market - Global Outlook and Forecast 2022-2027" by ResearchAndMarkets.com (2022):** This report provides insights into the global industrial automation market, including trends in specific segments like robotics and pick-and-place systems, offering valuable market context.
- **"The Future of Industrial Robotics 2023-2028" by BIS Research (2023):** This report explores the future of industrial robotics, highlighting key trends and applications relevant to your project, keeping you informed about advancements.
- **"Southeast Asia Robotics Market - Growth, Trends, and Forecasts (2023 - 2028)"** by Technavio (2023): This report focuses on the robotics market in Southeast Asia, which might offer valuable insights into regional trends and potential suppliers for your project, considering your location.

4. Case Studies:

- **"Case Study: Automated Assembly of Brushless DC Motor Drives"** by Universal Robots: This case study describes how a company automated the assembly of brushless DC motor drives using robots, potentially offering inspiration for your H-bridge assembly process.
- **"Robotics in Electronics Manufacturing: Success Stories and Best Practices"** by Robotics Business Review: This article compiles various case studies showcasing successful applications of robotics in electronics manufacturing, providing valuable ideas for your project.

5. YouTube Videos: In addition to written resources, we found several YouTube videos relevant to our research:

- Automated Assembly Line for Electronics Manufacturing: This video showcases an automated assembly line for electronics manufacturing, providing insights into the integration of robotics and automation in the assembly process.
- Flexible Pick-and-Place Robot in Action: This video demonstrates a flexible pick-and-place robot in action, highlighting its capabilities in handling delicate components and adapting to various assembly tasks.
- Vision-Based Alignment System Demo: This video showcases a vision-based alignment system in operation, illustrating its role in achieving precise placement of components during assembly processes.
- Case Study: Automated Assembly of Motor Drives: This video presents a case study of automated assembly for motor drives, offering insights into real-world applications of robotics and automation in electronics manufacturing.

Our literature review encompassed an extensive exploration of existing automated assembly mechanisms and motor controlling H-bridges. Key findings from research papers include challenges and potential solutions as follows:

- **Challenges:**
    - Difficulty in handling delicate components like metal rings without damage.
    - Maintaining placement accuracy for high-density TRANSISTOR arrays.
    - Limited automation of H-bridge assembly processes, particularly for customized configurations.
- **Solutions:**
    - Flexible pick-and-place robots with adaptive grippers: We explored solutions such as those available on the Open Robotics website and considered On Robot solutions.
    - Vision-based alignment systems: Utilizing vision-based systems for precise placement of components.
    - Development of custom automated assembly processes: Tailored approaches to address the specific design complexities of H-bridges.

B) Proposed Robotic Arm System

1. **Arm Configuration**

The robotic arm system is engineered to pivot and assemble parts into a ring configuration. It employs two sliders for precise manipulation along the x and z axes, enabling accurate positioning. With the integration of three stepper motors, the robotic fingers boast exceptional dexterity and gripping capabilities, facilitating versatile movement and meticulous assembly.

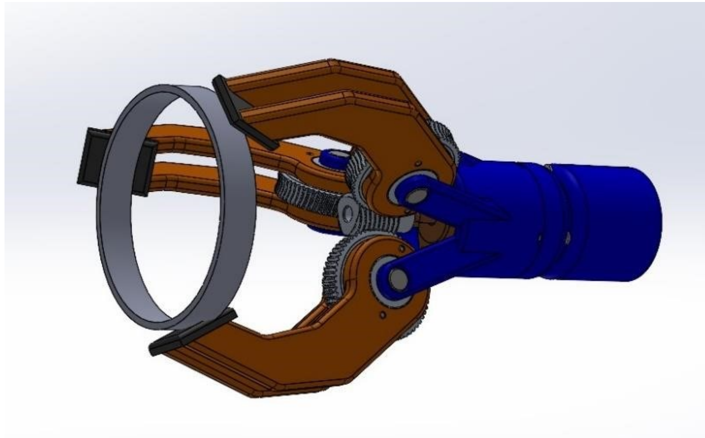

Figure 1 - Designed proposed Arm part for grabbing scenario

2. **Robot Selection**

Selection criteria for the robotic arms encompass considerations such as payload capacity, accuracy, speed, and reach. Special attention is given to collaborative robots for their inherent safety features, ensuring seamless interaction with human operators and adaptability to dynamic production requirements.

3. **Programming and Control**

The development of an intuitive programming interface allows for a seamless definition of assembly sequences and motion paths. Comprehensive safety protocols and error-handling routines are implemented to guarantee the secure and reliable operation of the robotic arm system.

C) Key Features and Innovations

The development of the industrial robot arm for precise placement and rotation of metal rings in the riveting process incorporates several key features and innovations. These include:

- Multi-axis motion control: The robot arm is designed to move with precision along multiple axes, ensuring accurate positioning and rotation of the metal rings during the riveting process.
- Customization and integration of grippers: Specialized grippers are customized and integrated into the robot arm system to securely hold the metal rings in place during manipulation.
- Implementation of vision systems for object detection: Advanced vision systems are employed to detect the position and orientation of the metal rings, enabling the robot arm to adjust its movements accordingly for precise placement and rotation.

- Advancements in robotic manipulation techniques: Innovative techniques are employed to enhance the robot arm's manipulation capabilities, allowing for smooth and accurate handling of the metal rings throughout the riveting process.

1. **Development Plan**

The comprehensive development plan encompasses various elements tailored specifically for the precise placement and rotation of metal rings in the riveting process. These elements include:

- Modular robot arm design: The robot arm is designed in a modular fashion to facilitate easy customization and adaptation to different riveting setups and requirements.
- Utilization of advanced sensing technologies: State-of-the-art sensing technologies are utilized to provide real-time feedback on the position, orientation, and condition of the metal rings, ensuring precise handling and alignment.
- Formulation of control algorithms: Advanced control algorithms are developed to coordinate the movements of the robot arm and optimize its performance for accurate placement and rotation of the metal rings.
- Rigorous testing and validation procedures: Extensive testing and validation procedures are conducted to ensure the reliability, accuracy, and efficiency of the robot arm system in the riveting process.
- Collaboration with industry partners: Collaboration with industry partners is fostered to gather insights, feedback, and expertise in metalworking processes, further enhancing the development and optimization of the robot arm system.

2. Next Steps

The subsequent steps involve the synthesis of the technologies mentioned above, aiming to create a robust and efficient system tailored specifically for the precise placement and rotation of metal rings in the riveting process. These steps include further refinement of the control algorithms, optimization of the robot arm's performance, and integration of additional features to enhance its capabilities in metalworking applications. Additionally, ongoing collaboration with industry partners will continue to drive the development process forward, ensuring the eventual deployment of a highly reliable and effective solution for the riveting process.

D) Combined Project Plan

Objectives

- Achieve precise placement and rotation of metal rings for the riveting process.

- Utilize a moving robotic arm system with specialized mechanisms for accurate handling.

Action Plan

1. Development of the robotic arm:
    - Design and construction of a robotic arm system.
    - Capable of precisely placing and rotating metal rings during the riveting process.
2. Programming and control implementation:
    - Development and implementation of software algorithms.
    - Control the movements and actions of the robotic arm system for precise manipulation.
3. Integration of vision systems:
    - Implementation of advanced vision systems for object detection.
    - Detect the position and orientation of metal rings to adjust robotic arm movements accordingly.
4. Customization of grippers:
    - Customization and integration of grippers into the robotic arm system.
    - Securely hold metal rings in place during manipulation for precise handling.
5. Thorough testing and validation:
    - Rigorous testing procedures to ensure reliability and accuracy of metal ring placement and rotation.

Next Steps

1. Progress with the design and prototyping phase of the robotic arm system.
2. Explore potential suppliers for specialized components required for precise manipulation.
3. Develop and refine software algorithms for accurate control of the robotic arm system.
4. Implement advanced vision systems for object detection and orientation adjustment.
5. Conduct thorough testing and validation to verify the precision and efficiency of the robotic arm system.

3. Stakeholder Map

A stakeholder map has been devised to identify and categorize the primary stakeholders involved in the project:

- **Project Team**: Responsible for designing, developing, and testing the robotic arm system.
- **Industry Partners**: Collaborators offering insights, feedback, and potential deployment opportunities.
- **Suppliers**: Providers of essential components ensuring the quality and compatibility of the robotic arm system.
- **Research Institutions**: Collaborative partners contributing to technological advancements and expertise.
- **End Users**: The manufacturing industry, benefits from the automated assembly process.

4. Observing User Requirements for the Metal Ring Placement and Rotation

To meet the expectations of stakeholders and ensure the successful implementation of the Metal Ring Placement and Rotation project, the following user requirements have been identified and meticulously observed:

1. Precision in Placement and Rotation

The system must achieve high precision in both the placement and rotation of metal rings within the H-Bridge assembly. Accurate placement and rotation are crucial for ensuring the proper functioning and alignment of the metal rings, which directly impacts the performance of the H-Bridge. The system should be capable of consistently positioning the metal rings with minimal deviation from the desired location and orientation, thereby maintaining the quality and reliability of the assembled units.

2. Flexibility and Adaptability

The system should be flexible and adaptable to handle various sizes and types of metal rings used in different H-Bridge designs. This adaptability allows the system to accommodate a range of specifications and requirements, ensuring that it can be used across multiple production lines and applications. Quick adjustments or changes in tooling should be possible to facilitate the handling of different ring sizes and materials, enhancing the system's versatility.

3. Ease of Integration

The system must be designed for easy integration into existing production lines and should be compatible with standard industrial communication protocols. This compatibility ensures that the system can seamlessly connect with other equipment and control systems, facilitating smooth operation and coordination within the production environment. The integration process should be straightforward, minimizing disruptions to ongoing operations and reducing setup time.

4. Automation and Efficiency

The system should support full automation to enhance production efficiency and reduce the need for manual labor. By automating the placement and rotation processes, the system can achieve higher throughput and consistency, leading to increased productivity. The system should be capable of operating autonomously with minimal human intervention, focusing on delivering efficient and reliable performance in a high-volume production setting.

5. User Interface and Control

The system must include a user-friendly interface that allows for easy operation and monitoring. The interface should be intuitive and provide clear controls for managing the system's functions. Real-time monitoring capabilities and diagnostic tools should be incorporated to help users quickly identify and address any issues, ensuring smooth and efficient operation.

6. Safety and Compliance

The system must comply with relevant safety standards to ensure safe operation and protect users. Safety features such as emergency stop buttons, protective enclosures, and safety interlocks should be included to prevent accidents and injuries. The system should be designed to meet or exceed industry safety regulations, ensuring a safe working environment for all operators.

7. Cost-Effectiveness

The system should provide a cost-effective solution that balances initial investment with long-term operational savings. It should help reduce overall production costs by minimizing the need for manual labor and increasing efficiency. The design should focus on delivering value over its operational lifetime, providing a return on investment through improved productivity and reduced maintenance costs.

5. Review of Existing Products for Metal Ring Placement and Rotation

In the current market, two notable products for metal ring placement and rotation automation stand out. Yaskawa Motoman's MH24 Robot is a versatile robotic arm widely used in precision assembly tasks, including the placement and rotation of components like metal rings. It features advanced motion control and integrated vision systems, which enable high accuracy and speed, making it ideal for complex assemblies in various industries. Its flexibility to handle different sizes and types of rings, along with user-friendly programming, positions it as a leading solution for automated assembly lines. Another prominent product is the FANUC M-20iB/25 Robot, known for its robust performance in high-precision tasks. It offers seamless integration with vision systems and provides excellent repeatability and positioning accuracy. This robot is particularly valued for its ability to adapt to diverse production needs, ensuring efficient handling and placement of metal rings. Both products exemplify the cutting-edge capabilities of current automation technology, offering significant enhancements in productivity and consistency for industrial applications.

6. Design concepts and Evaluation

Our conceptual design approach is based on three key principles: precision, flexibility, and efficiency. We have developed three design sketches accompanied by functional block diagrams to illustrate our proposed concepts.

Design Sketches:

1. <u>Sketch 1</u>

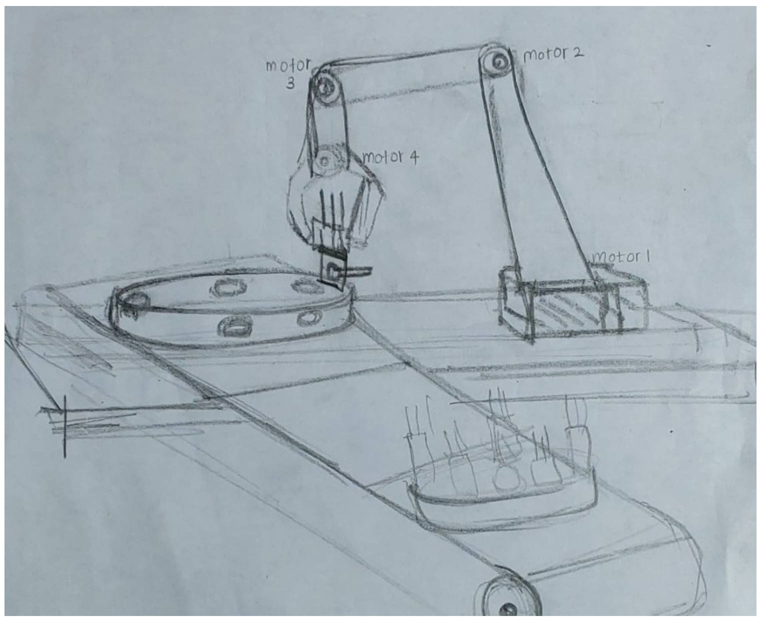

Figure 1: Sketch 1

This design features a robotic arm system with 3 degrees of freedom (3DOF) and rotational fingers. It utilizes a conveyor belt to bring the metal ring, along with the assembled transistors, washers, and rivets, to the robot arm for pick-up and placement. The arm is capable of freely moving to execute these tasks.

1.1 Functional Block Diagram

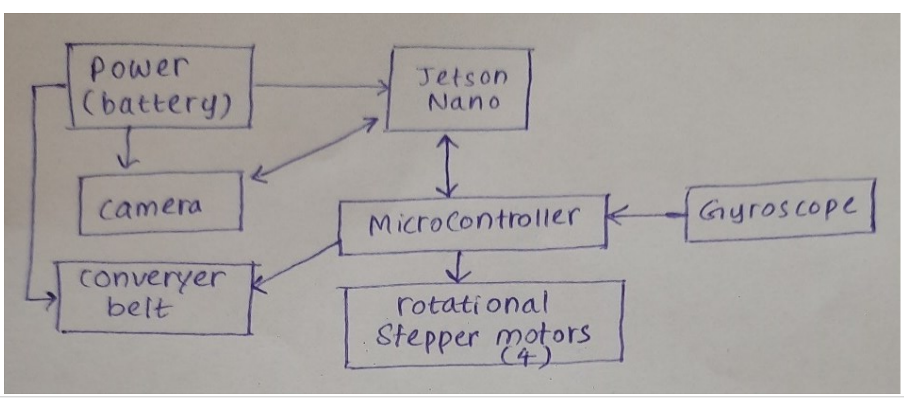

Figure 2: Block diagram for sketch 1

1.2 Reasons to Refuse Sketch 1:

- **Complexity:** Incorporating a conveyor belt adds complexity to the system, potentially leading to synchronization issues and maintenance challenges.
- **Practicality Concerns:** Maintenance and reliability issues associated with conveyor systems may reduce practicality in real-world applications.
- **Integration Challenges:** Coordinating the robotic arm with the conveyor belt requires additional mechanisms and may pose integration challenges.

2. <u>Sketch 2</u>

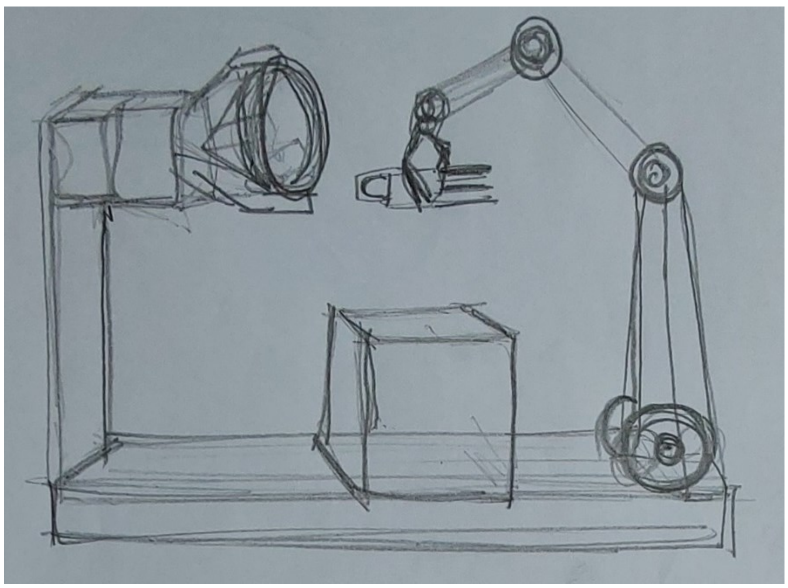

Figure 3: Sketch 2

Similar to Sketch 1, this design features an articulated robotic arm with multiple revolute joints for enhanced flexibility and maneuverability. Instead of using a conveyor belt, it incorporates a movable and rotatable finger to rotate the metal ring.

2.1 Functional Block Diagram:

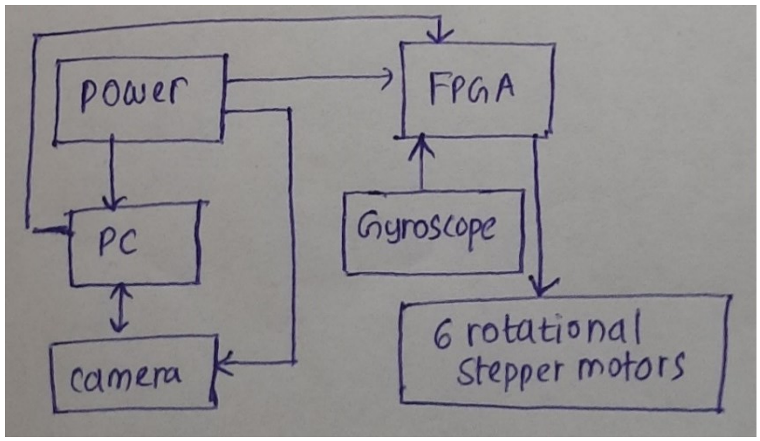

Figure 4: Block diagram for sketch 2

- Joint Control System
- Gripper Mechanism
- Feedback Loop for Accurate Positioning

2.2 Reasons to Refuse Sketch 2:

- **Complexity:** The articulated arm design introduces complexity with multiple revolute joints and additional moving parts.
- **Maintenance Risks:** Increased mechanical complexity may lead to higher maintenance requirements and potential reliability issues.
- **Limited Practicality:** Reliability concerns and maintenance requirements may reduce the practicality of the design for industrial applications.

3. <u>Sketch 3</u>

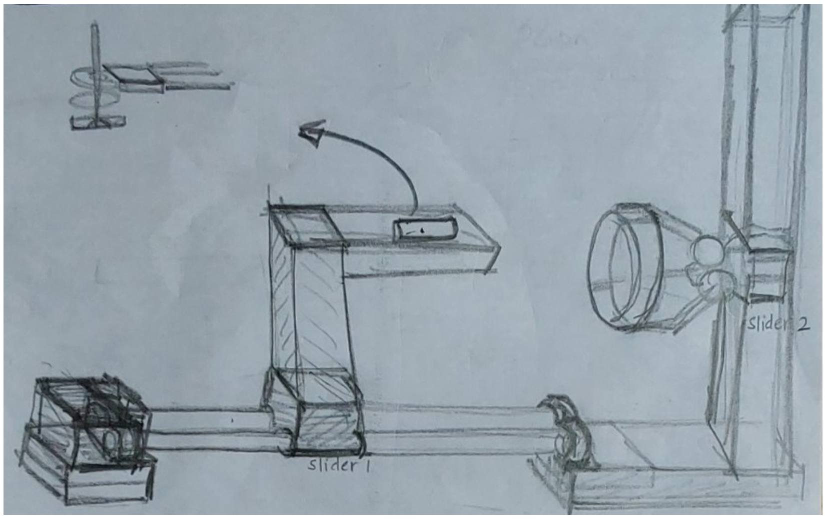

Figure 5: Sketch 3

This design utilizes stepper motors for motion control along the X and Y axes, as well as rotation. It features simplicity in design with three stepper motors for precise motion control.

3.1 Functional Block Diagram:

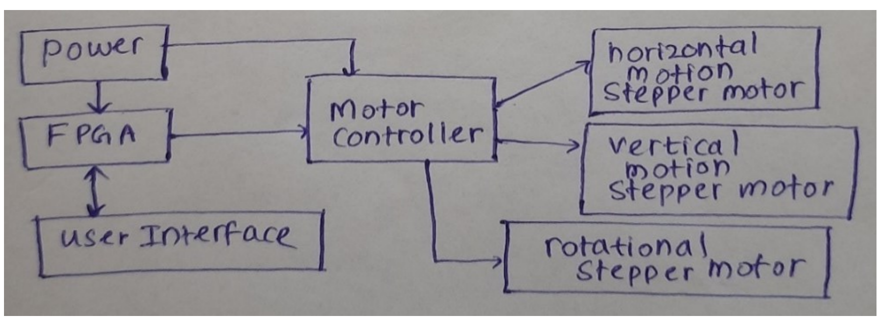

Figure 6: Block diagram for sketch 3

3.2 Reasons to Refuse Sketch 3:

- **Flexibility Limitations:** Stepper motors may limit the flexibility of the robotic arm compared to designs using servo motors or other actuators.
- **Smoothness of Movement:** Stepper motors may not provide as smooth and continuous motion as other types of actuators, potentially impacting efficiency.
- **Calibration Complexity:** Achieving and maintaining precise calibration with stepper motors may be challenging, leading to calibration complexities and potential performance issues.

4. <u>Sketch 4</u>

This design features XY motion, arm rotation, and finger motion, powered by four stepper motors. It includes the following components:

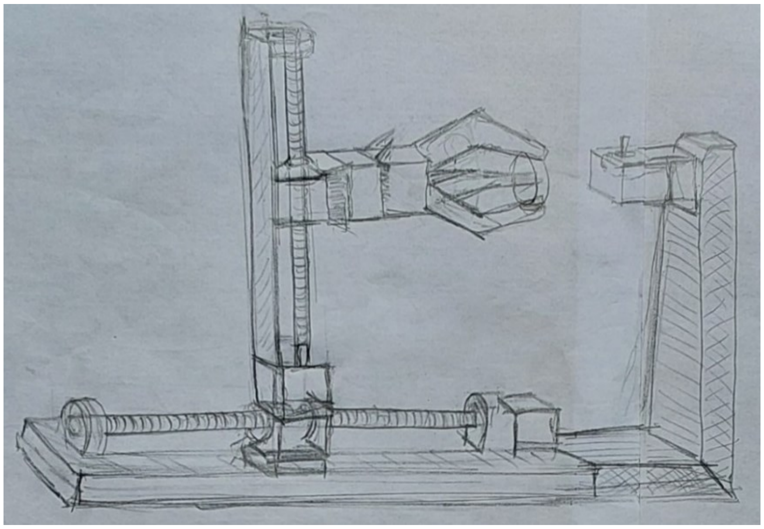

Figure 7: Sketch 4

4.1 Functional Block Diagram:

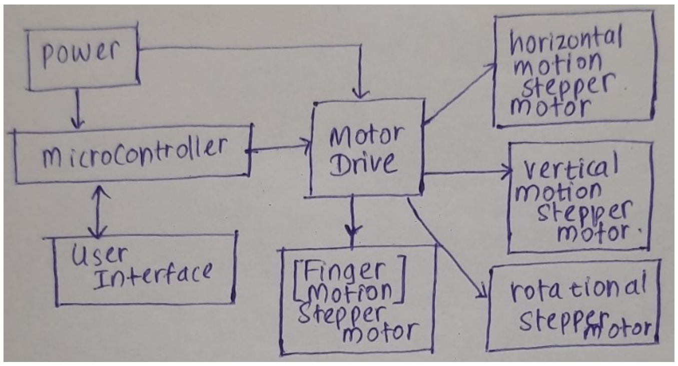

Figure 8: Block diagram for sketch 4

4.2 Reasons to Select Sketch 4:

- **Simplicity with Flexibility:** Sketch 4 offers a balance between simplicity in design and flexibility in functionality.
- **Smooth and Precise Movements:** Utilizing stepper motors ensures smooth and precise movements, crucial for accurate placement and rotation.
- **Adaptability and Integration:** Sketch 4's design allows for greater adaptability to varying assembly tasks and facilitates seamless integration of components.

- **Compatibility with Sub Task One:** Aligns closely with the requirements of Sub Task One, making it the most suitable option for achieving the desired outcome in the H-bridge assembly process.

Proposed Design

After careful evaluation, we propose to select the Robot Arm Design sketch 1 for our project. This choice is based on several factors:

- **Easy Implementation:** The design offers simplicity and straightforward construction, enabling rapid deployment in production environments.
- **Practicability:** With only linear and rotational movements, this design is practical for the precise placement and rotation of the metal ring.
- **Feasibility:** The robot arm can achieve the required level of precision and accuracy for our application.
- **Smooth Movements:** By controlling motion over the X-axis, Y-axis, and rotation, this design ensures smooth and controlled movements during the assembly process.
- **Adjustable Pivoting Placement:** The robot arm allows for adjustable pivoting placement, accommodating variations in the metal ring's position and orientation.

Robotic Arm Design Evaluation

Comparison among concepts.					
Concept Number		Concept 1	Concept 2	Concept 3	Concept 4
Added features		Conveyor belt	FPGA	Vibration Sensor	
		Machine learning	Machine learning	FPGA	Microcontroller
		Vision Camera	Vision Camera	Sliders	Sliders
Removed features			Jetson Nano	Rotation Arm	FPGA
Comparison between Mechanical parts	Functionality	7	7	7	9
	Heat dissipation	8	6	7	7
	Assembly	8	7	8	9
	Serviceability	7	7	8	8
	Simplicity	5	7	6	8
	Durability	8	7	8	9
	Efficiency	6	7	8	9
Comparison between Functional block diagram	Functionality	8	7	7	9
	User experience	8	7	6	8
	Feasibility	7	8	8	9
	Cost	4	7	8	6
	Performance	7	6	7	9
	Future proofing	7	6	6	8
	Power	9	8	7	7
Total		99	97	101	117

Challenges and Considerations

While the Robot Arm Design offers numerous advantages, we acknowledge potential challenges and considerations:

- Sensing and Perception: Implementing robust sensing and perception systems to detect and adjust for variations in the metal ring's position and orientation.
- Motion Planning: Developing efficient motion planning algorithms to optimize movement trajectories and minimize cycle times.
- Integration: Ensuring seamless integration with other components of the assembly line for a cohesive production process.

7. Finalized Selected Design

After evaluating the options, **Design 04** is selected for its balance of complexity, cost, efficiency, and ease of integration. Its dual-action gripper design simplifies the mechanical system and minimizes the footprint on the assembly line.

This design offers a balance between simplicity and functionality, providing smooth and precise movements necessary for accurate metal ring placement and rotation. Its adaptability and integration capabilities make it well-suited for industrial applications, aligning closely with the project's objectives and requirements.

Here below well detailed sketch of design 4 diagram included.

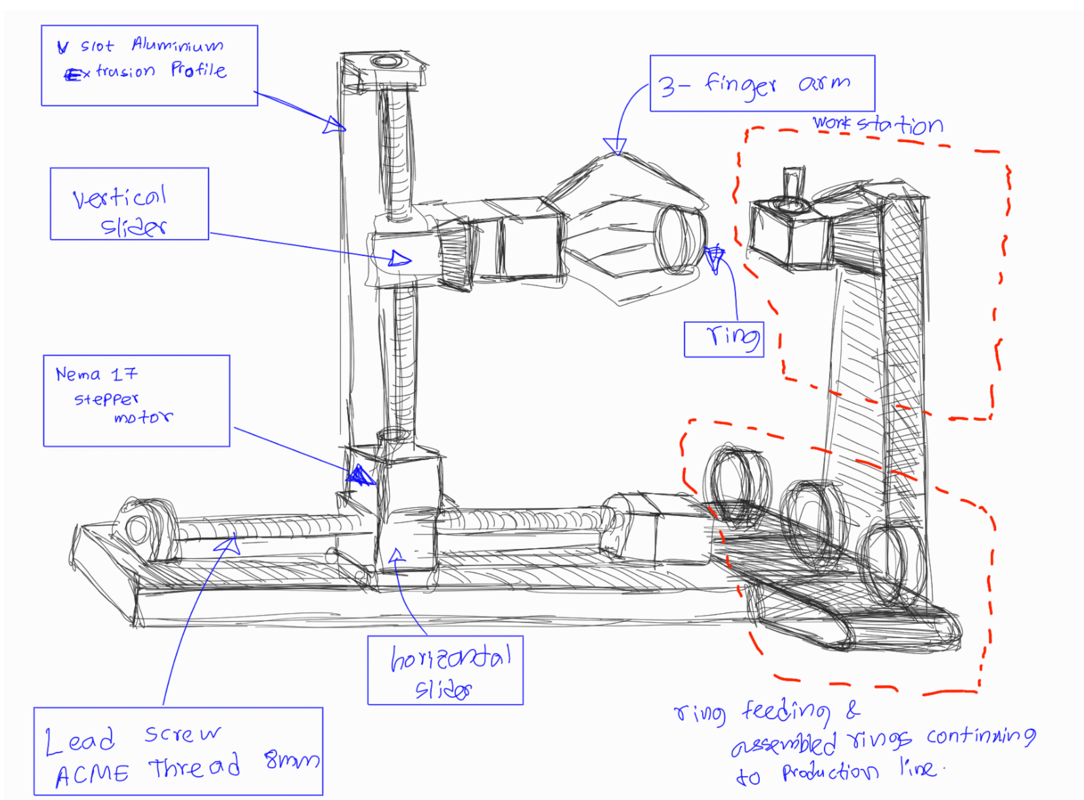

Figure 9 - Selected Design

8. Schematic Design

In the schematics design phase, each circuit component is meticulously mapped out to ensure proper functionality and integration. This involves drafting detailed diagrams that illustrate the connections between various electronic elements, such as resistors, capacitors, transistors, and integrated circuits. The layout must be clear and concise, with labels and annotations providing clarity on component values, pin configurations, and signal pathways. Attention to detail is paramount to avoid errors and ensure optimal performance. Additionally, considerations for power distribution, signal integrity, and thermal management are carefully incorporated into the schematics to guarantee reliable operation under varying conditions.

1. **Microcontroller Schematic (ATmega328P):** The microcontroller schematic incorporates the ATmega328P MCU along with support components such as crystal oscillator, decoupling capacitors, and programming header. It provides sufficient GPIO pins for motor control and communication interfaces such as SPI, and I2C.

2. **Power Schematic (LM7805):** The power schematic features the LM7805 linear voltage regulator to provide a stable 5V supply for the MCU and other components on the PCB. It includes input and output capacitors for filtering, as well as protection diodes for input voltage reverse polarity protection.

3. **Motor Driver Shield Schematic (A4988 * 4):** The motor driver shield schematic integrates four A4988 stepper motor driver ICs, each capable of driving one stepper motor. It includes protection diodes, current sensing resistors, and other necessary components for motor control. The schematic ensures efficient and precise control of stepper motors with micro stepping capability.

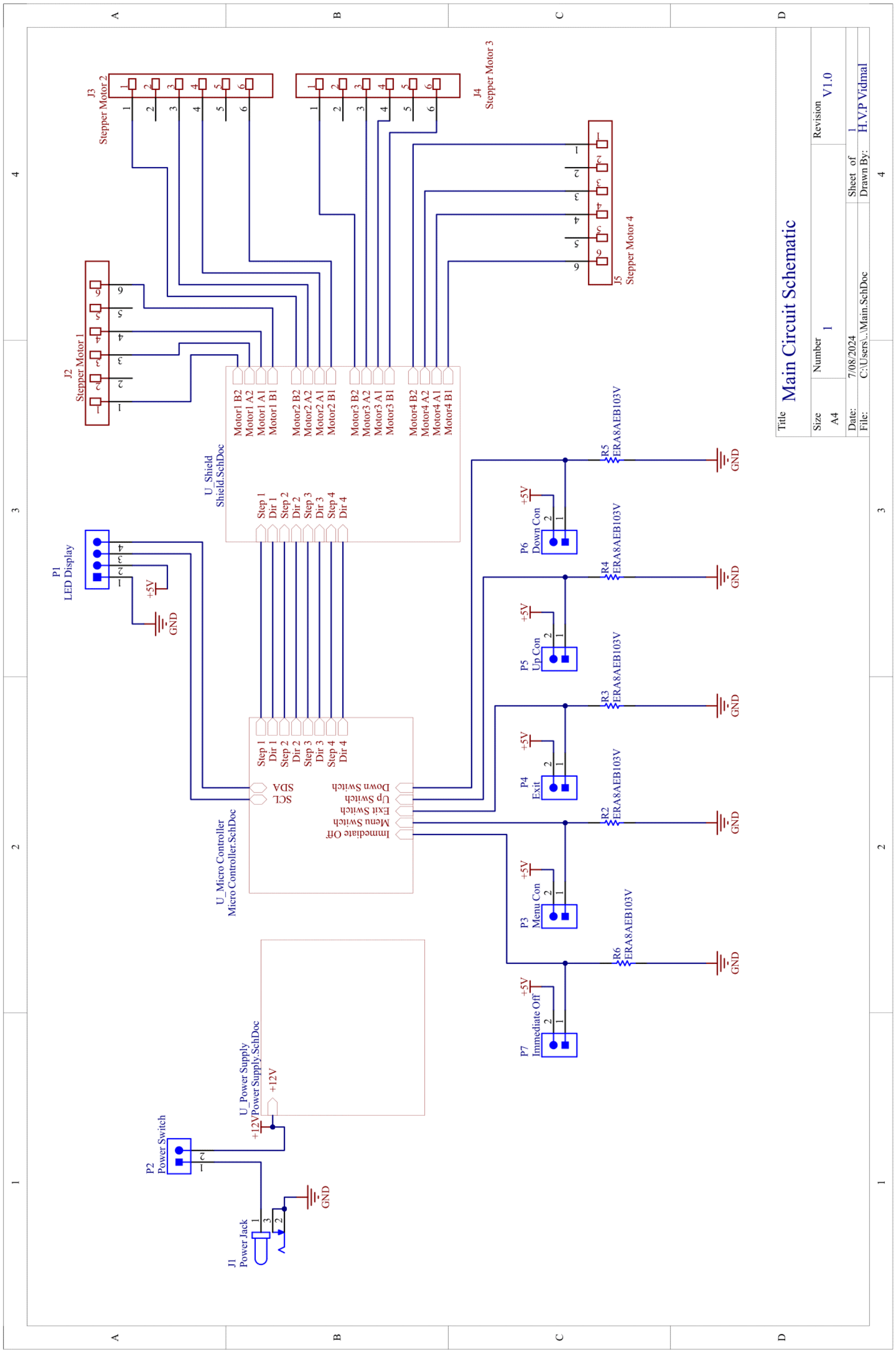

Figure 10: Main Circuit Schematic

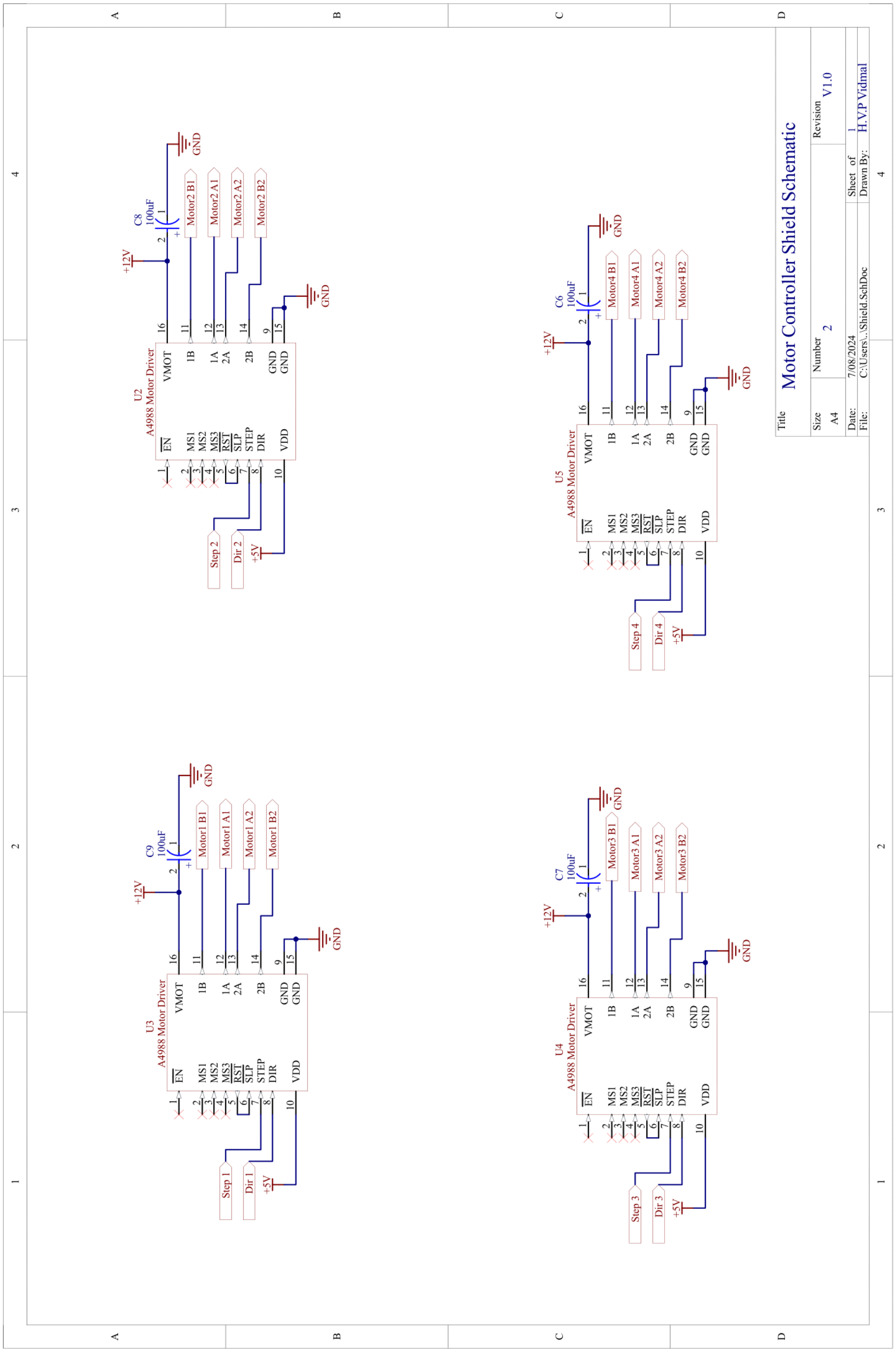

Figure 11: Motor Controller shield Schematic

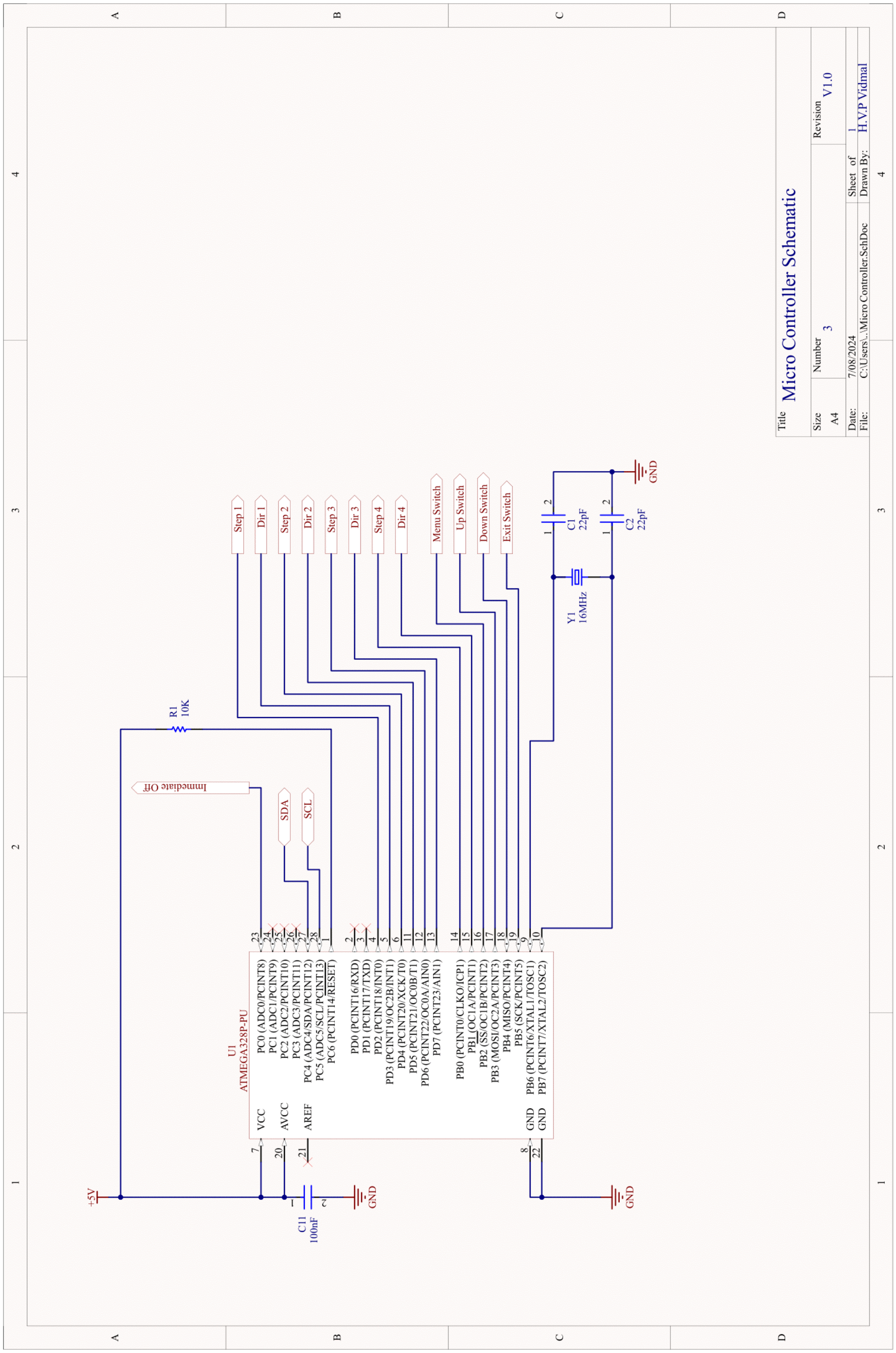

Figure 12: Microcontroller Schematic

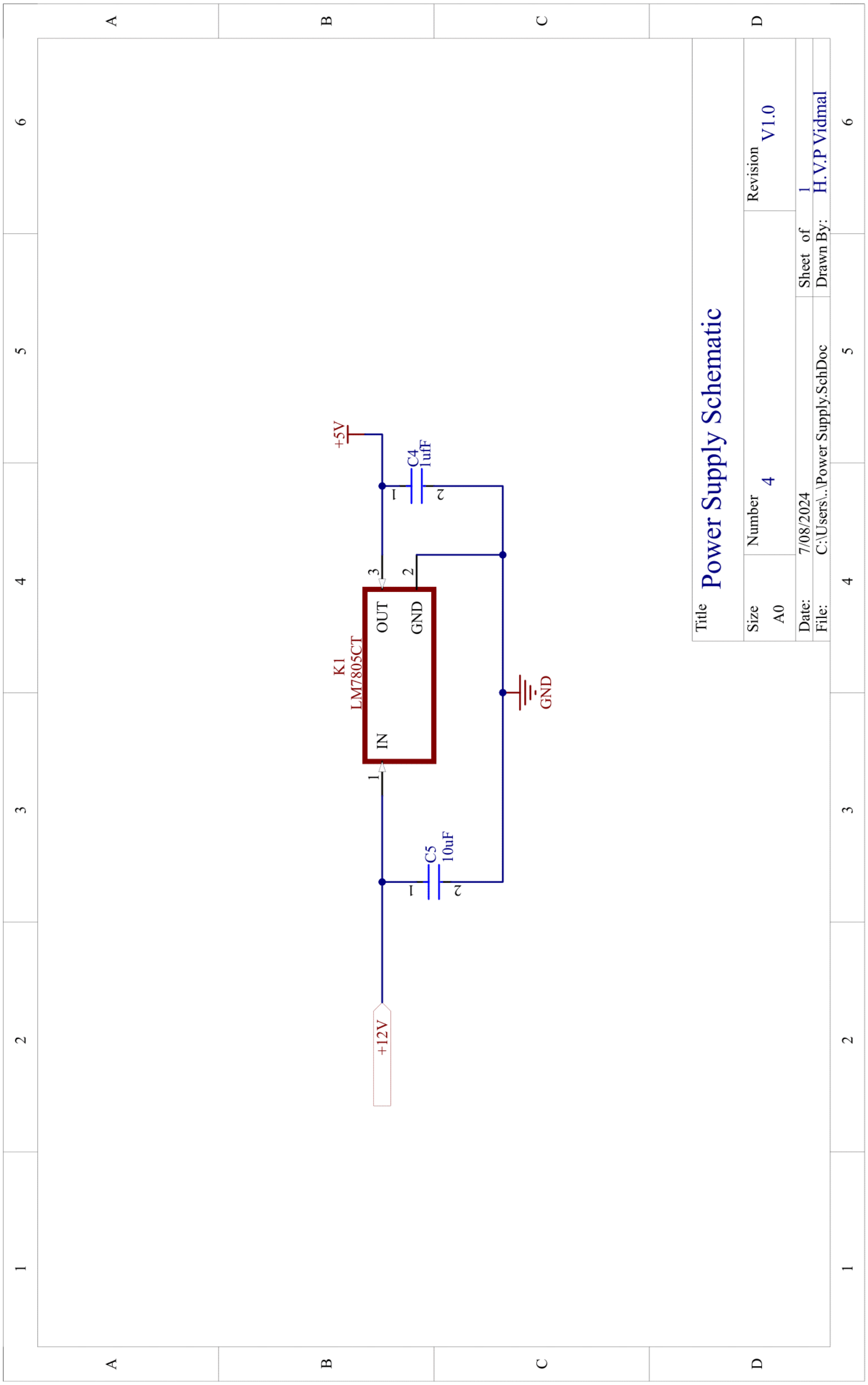

Figure 13: Power Supply Schematic

9. PCB Design

The PCB layout integrates all three schematics onto a single board, ensuring optimal component placement and signal routing. Key considerations include:

- **Traces**: Adequate width traces are used for power paths to minimize voltage drop and support the current requirements of the components. Signal traces are routed to minimize interference and maintain signal integrity.
- **Component Placement**: Components are positioned strategically to minimize trace lengths and optimize signal paths. Motor drivers are placed close to motor terminals to reduce noise and interference.
- **Ground Planes**: Ground planes are utilized to provide low impedance return paths and minimize ground loops. Separate ground regions are designated for analog and digital sections to prevent crosstalk and interference.
- **Thermal Management**: Heat dissipation for components such as the LM7805 voltage regulator and A4988 motor drivers is ensured through proper placement and possibly the addition of heat sinks or thermal vias.

Top Layer

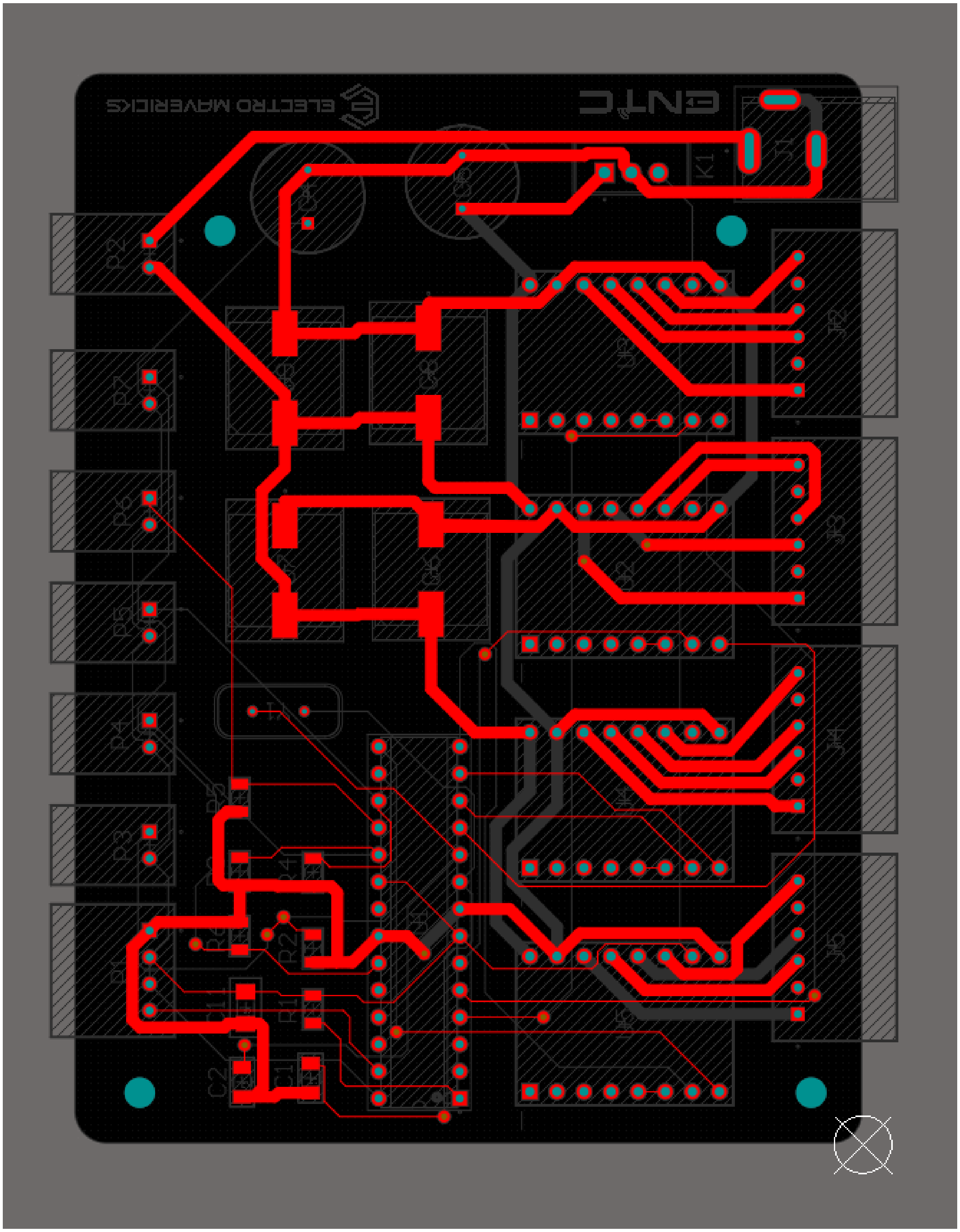

Figure 14: PCB design top layer

Bottom Layer

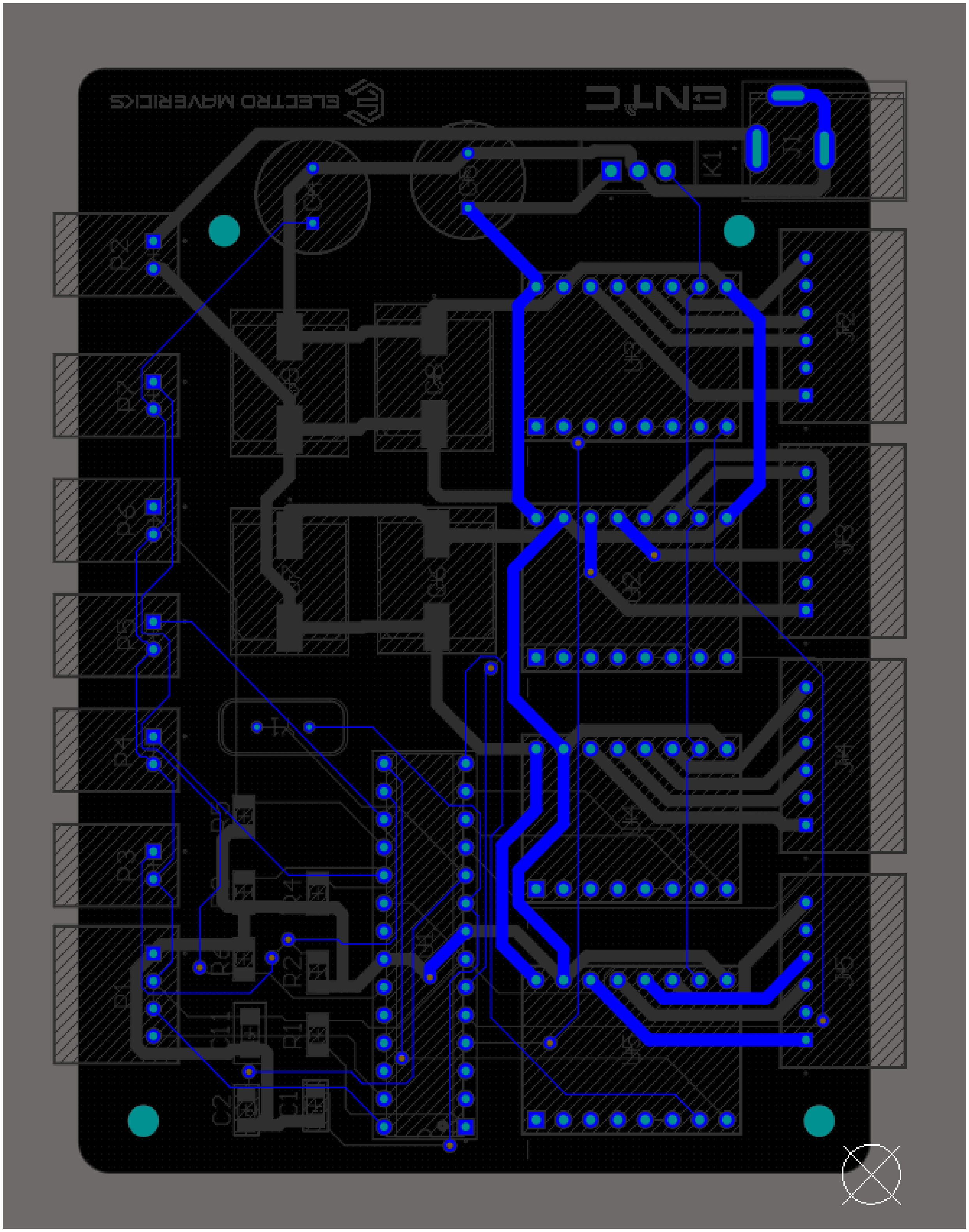

Figure 15: PCB design bottom layer

PCB with components

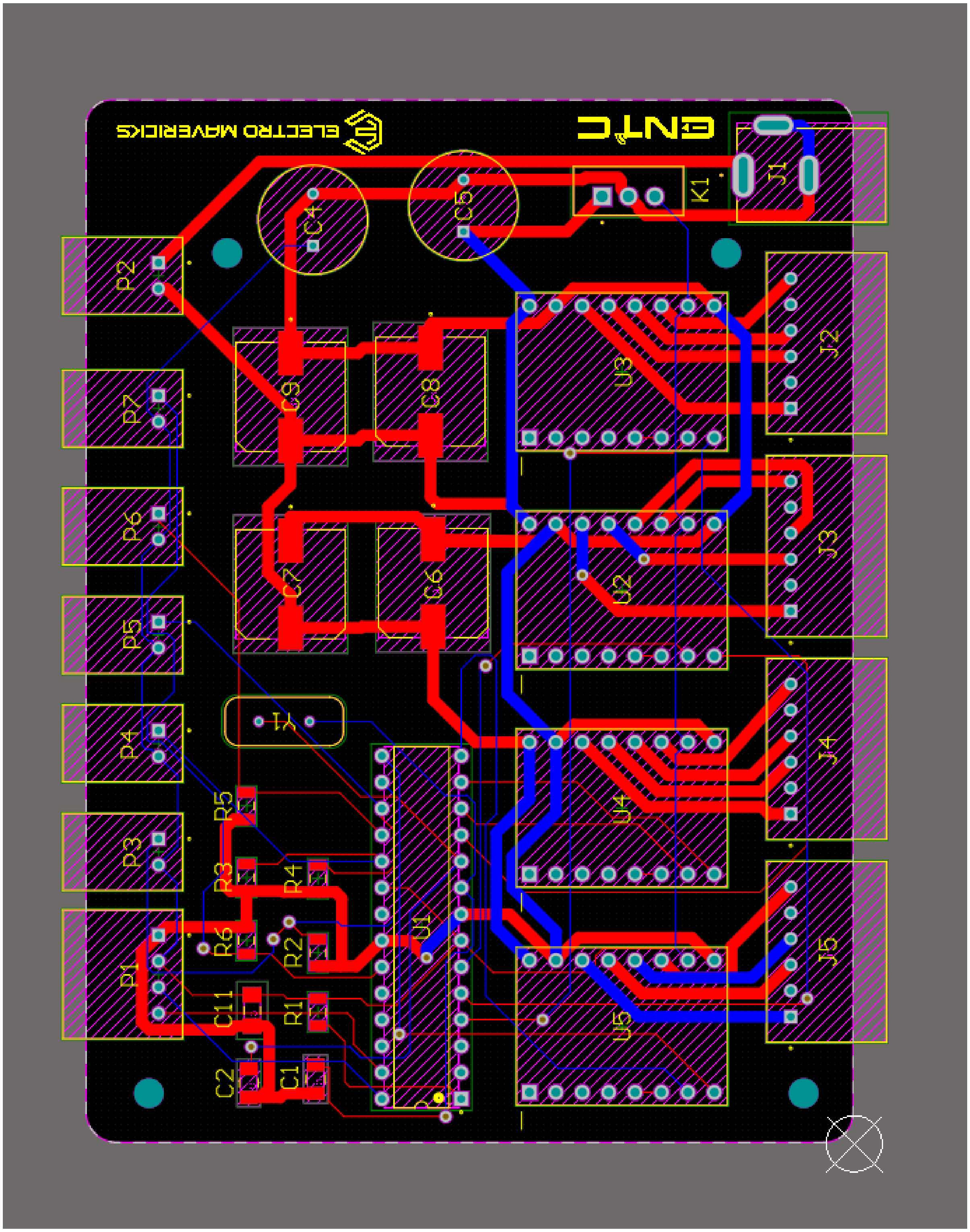

Figure 16: PCB design all layers

PCB 3D view

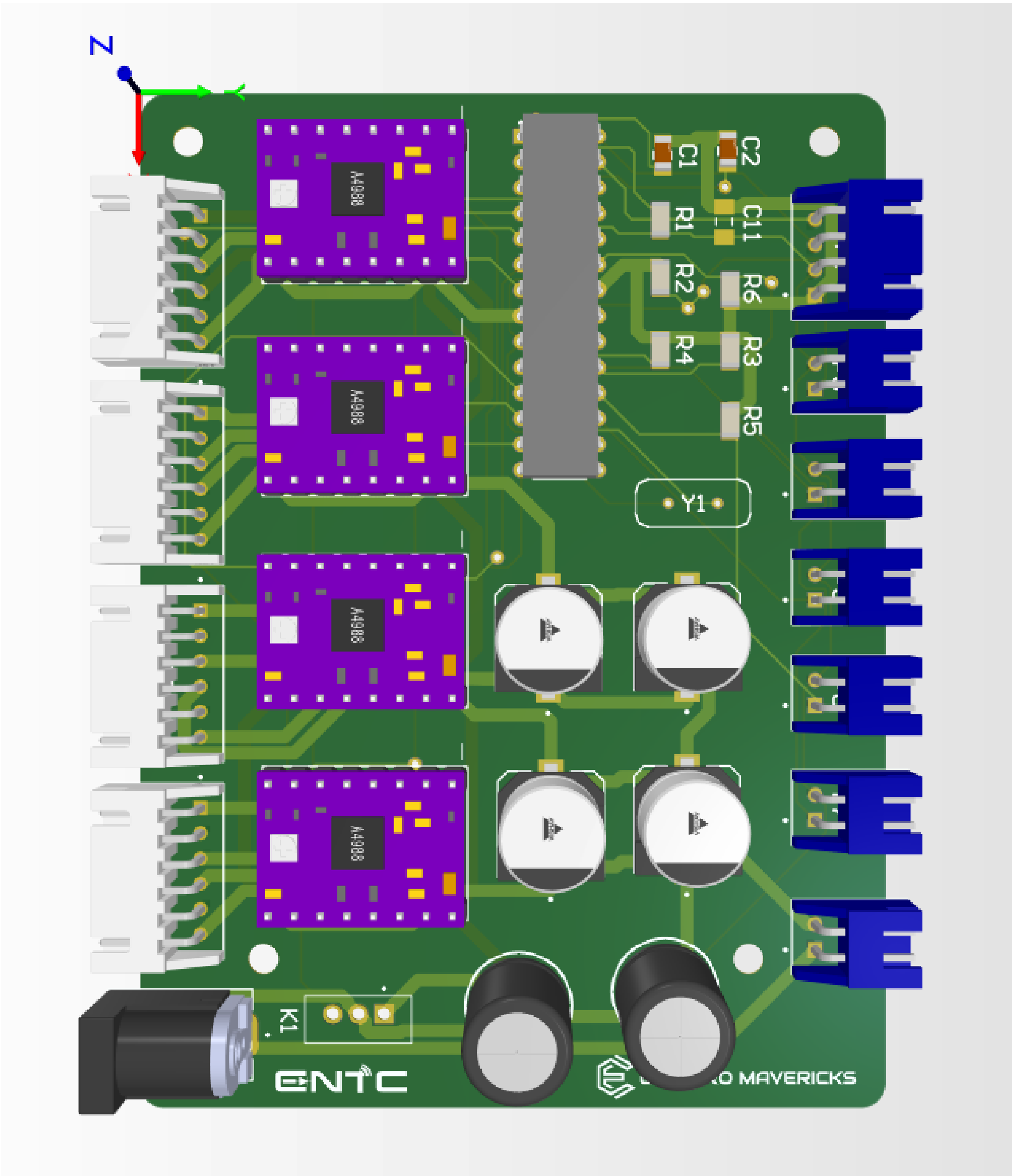

Figure 17: PCB design 3D view

10. SolidWorks Design

These images showcase the finalized SolidWorks design of the enclosure for the metal ring placement and rotation system. The enclosure is engineered with user-friendly features, facilitating easy interaction and operation for the end user. Constructed with durability in mind, the enclosure is robust and capable of withstanding impacts and various environmental conditions, ensuring long-term reliability.

The overall design is straightforward and cost-effective, striking a balance between meeting functional requirements and providing an aesthetically pleasing appearance. The design includes strategically placed holes for the insertion of buttons, allowing for the control of stepper motors, displays, and other components essential for system operation.

We employed parametric design tools in SolidWorks to create the enclosure, allowing for flexibility and easy modifications as needed. Additionally, anti-collapsing tests were conducted to ensure the structural integrity of the design, confirming that it meets all necessary safety and durability standards.

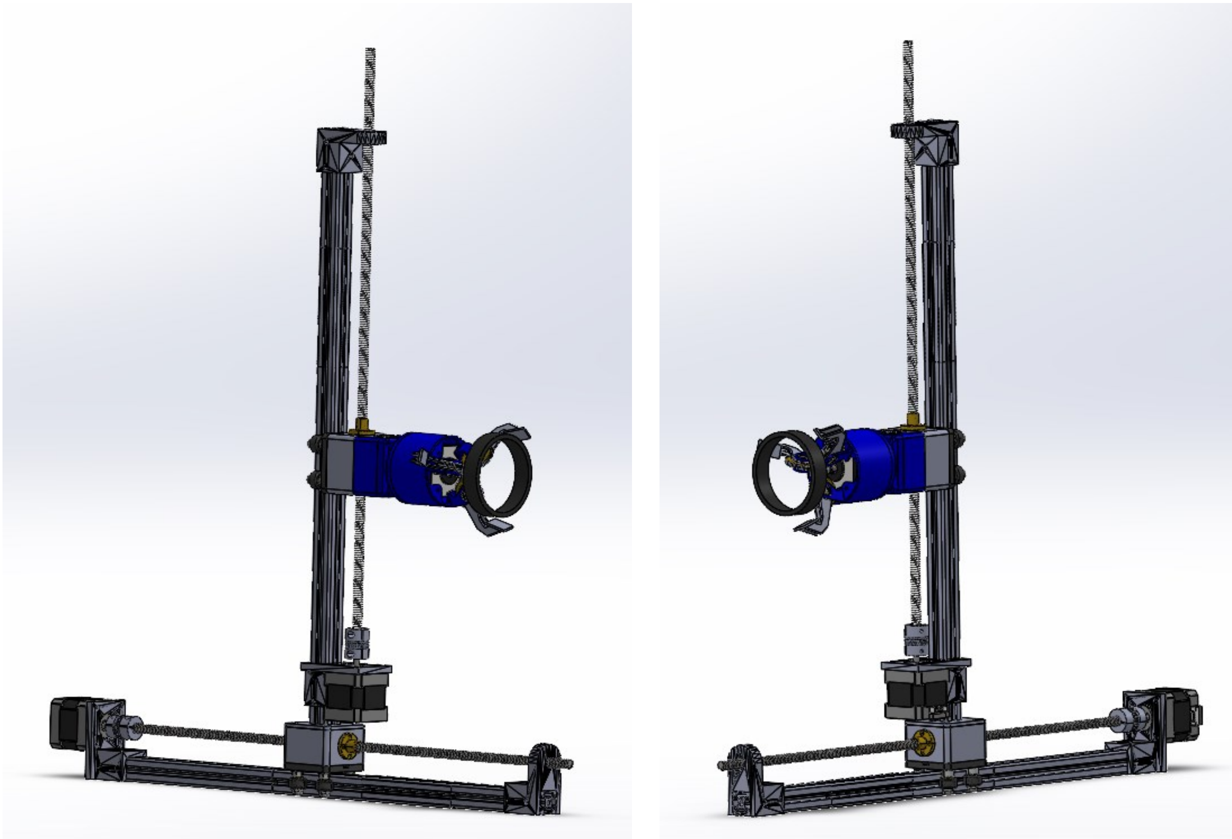

Figure 18: Final Design

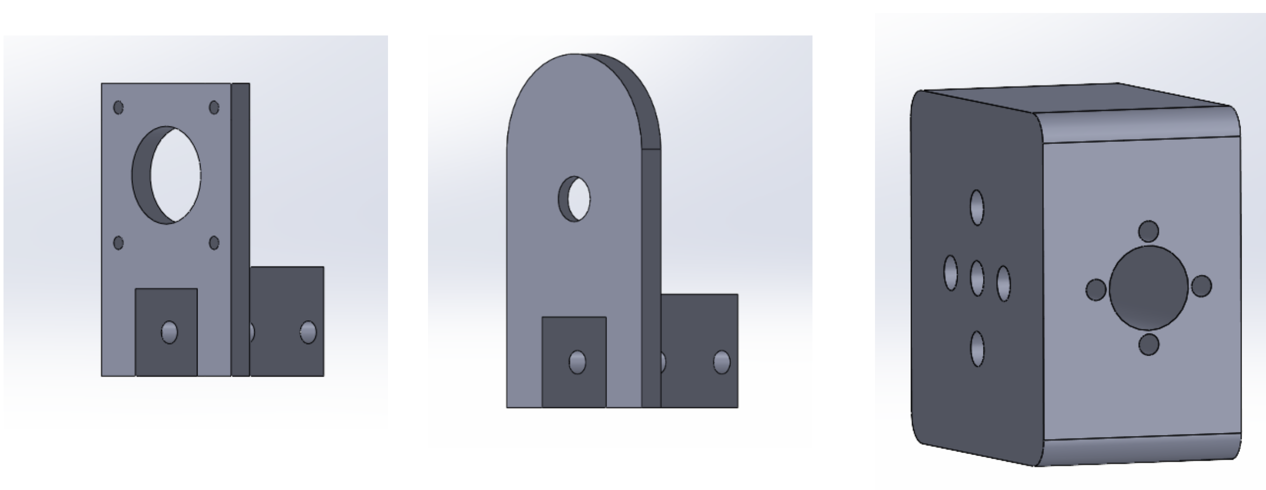

Figure 19: Supporters

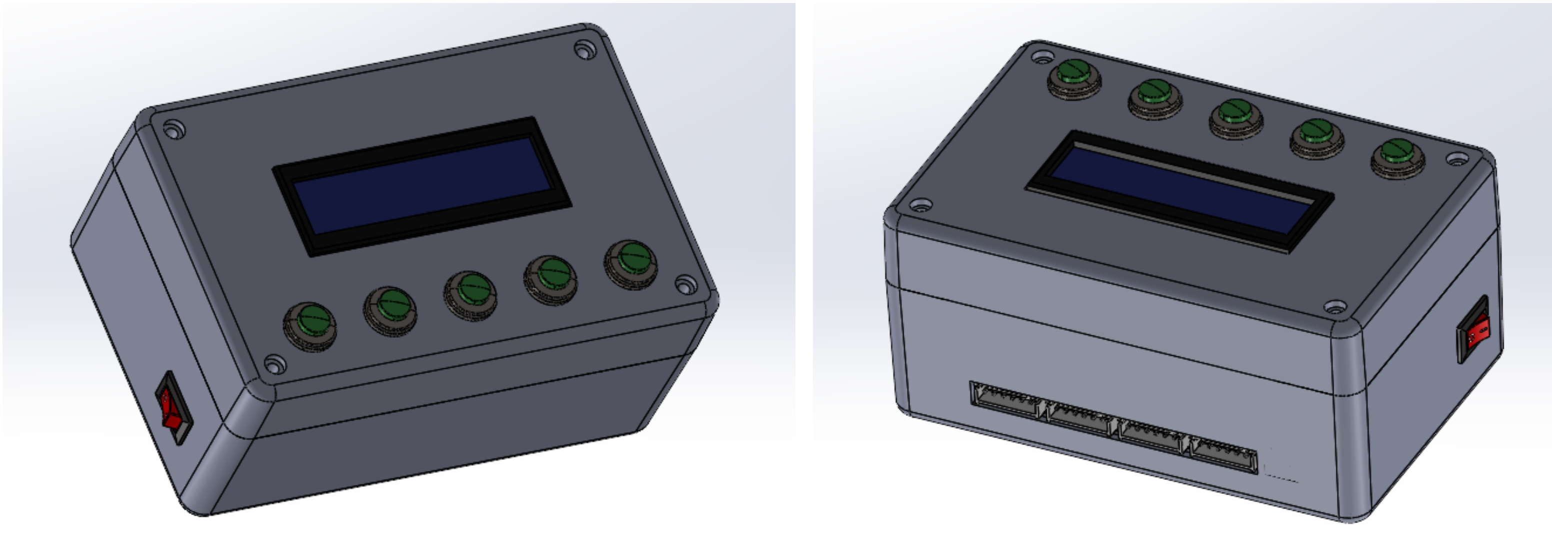

Figure 20: Enclosure
Figure 20:

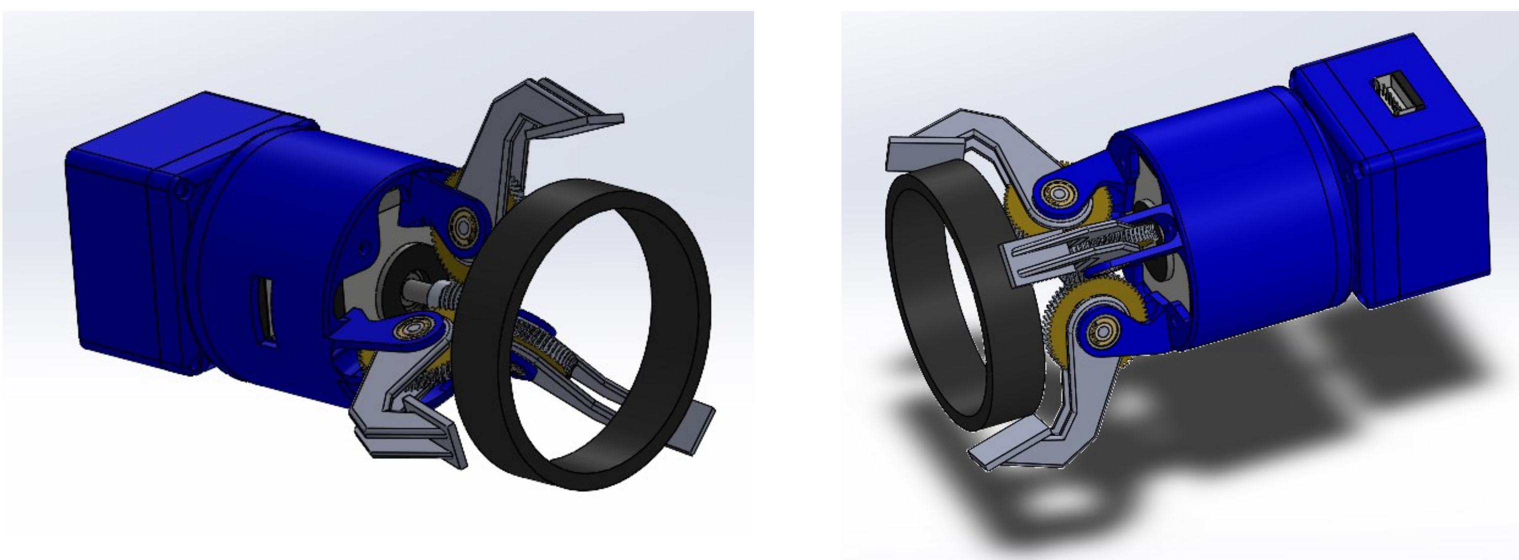

Figure 21: Gripper

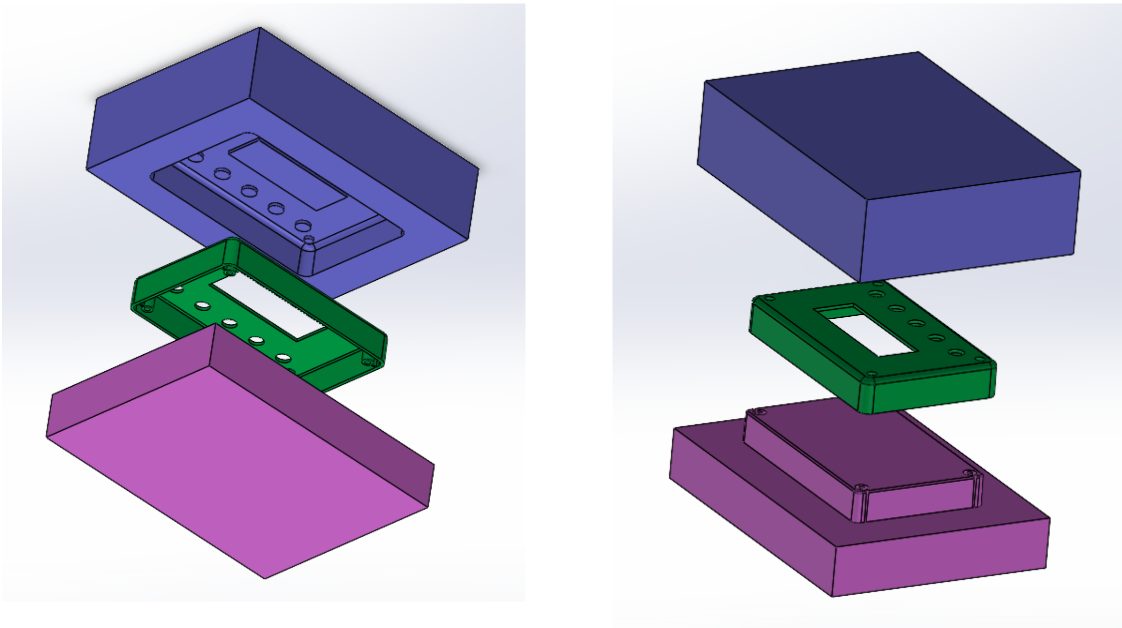

Figure 22: Mold Design – Enclosure Lid

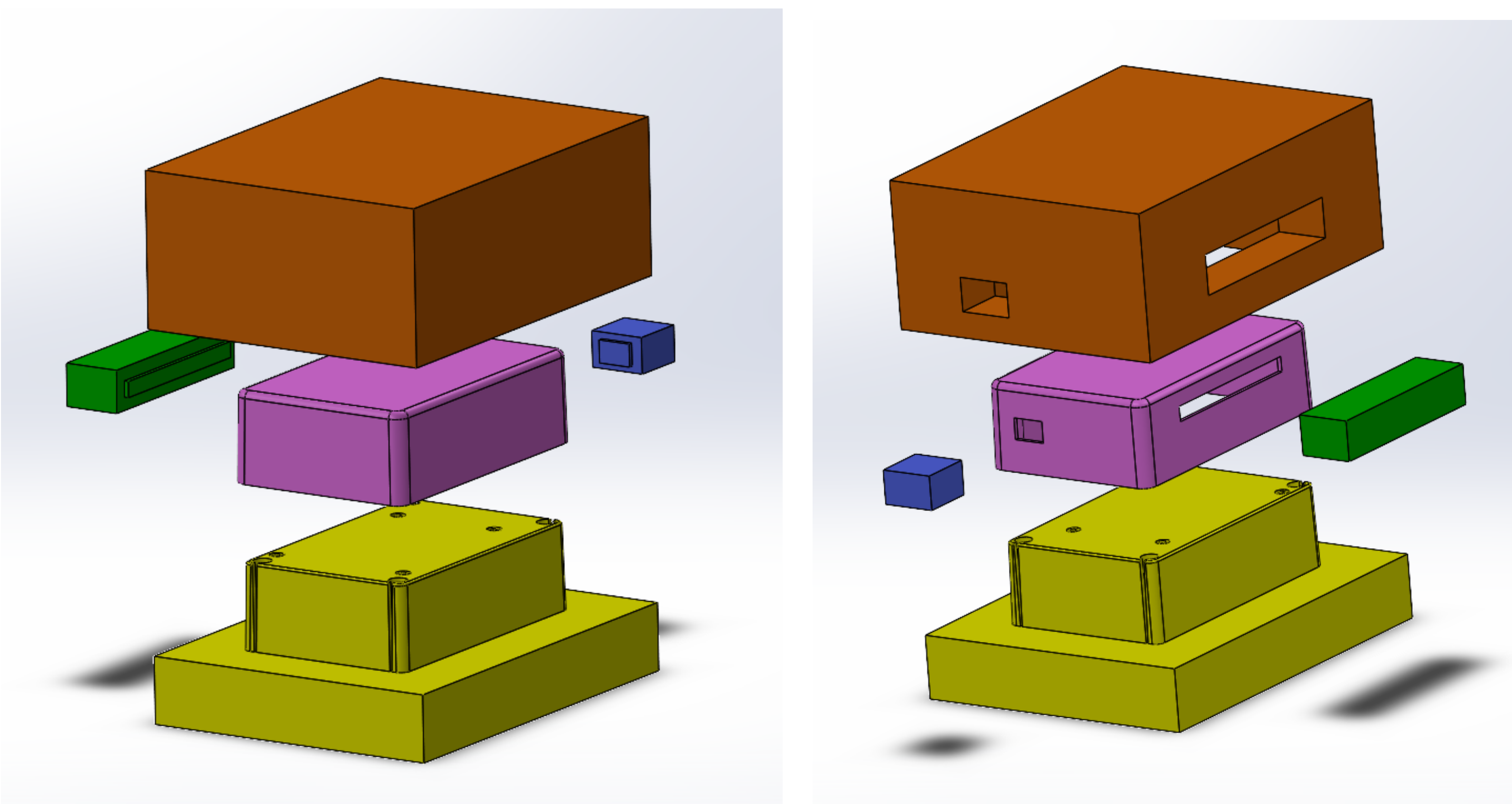

Figure 23: Mold Design – Enclosure box

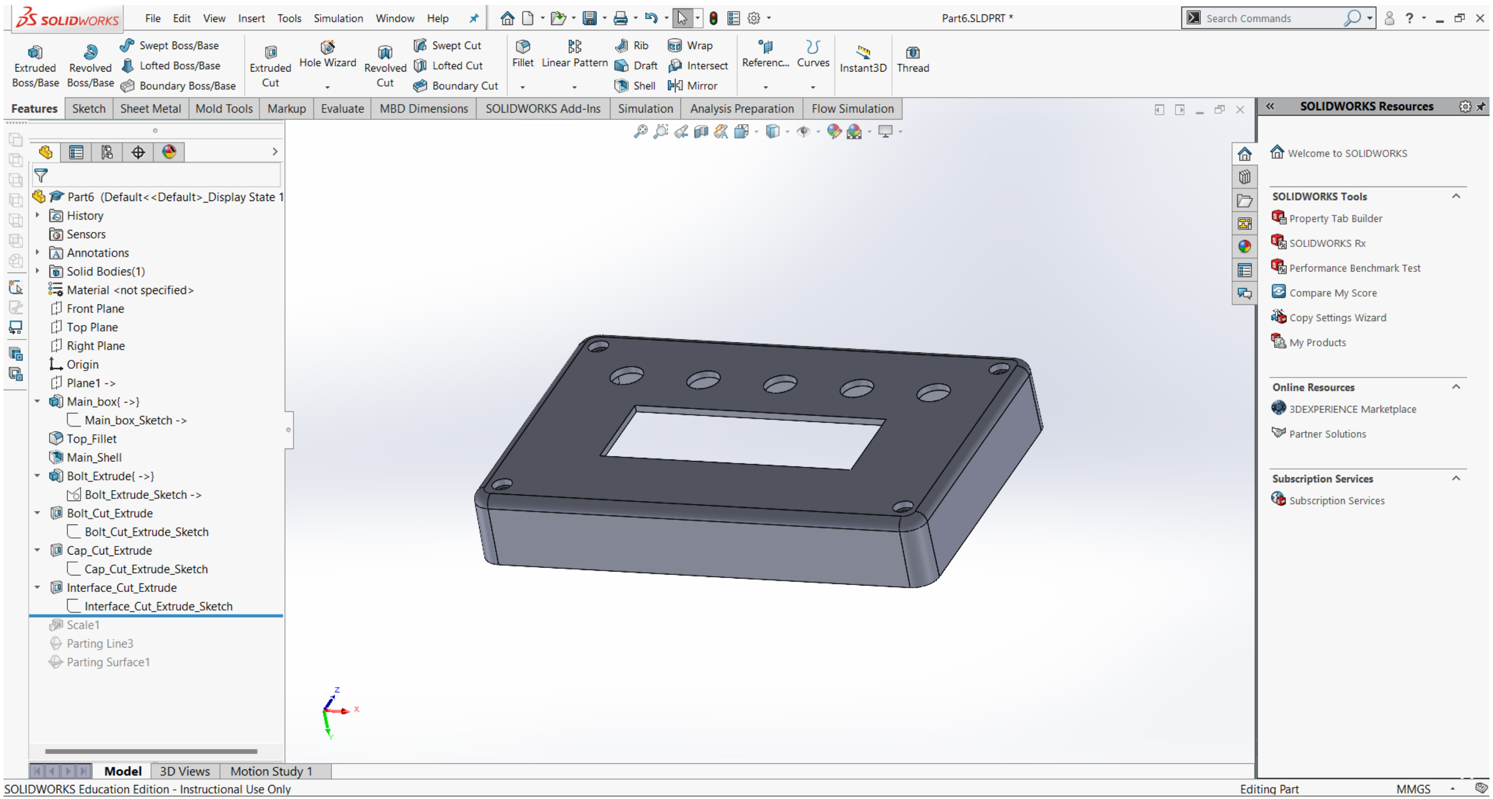

Figure 24: SolidWorks Design (Lid part)

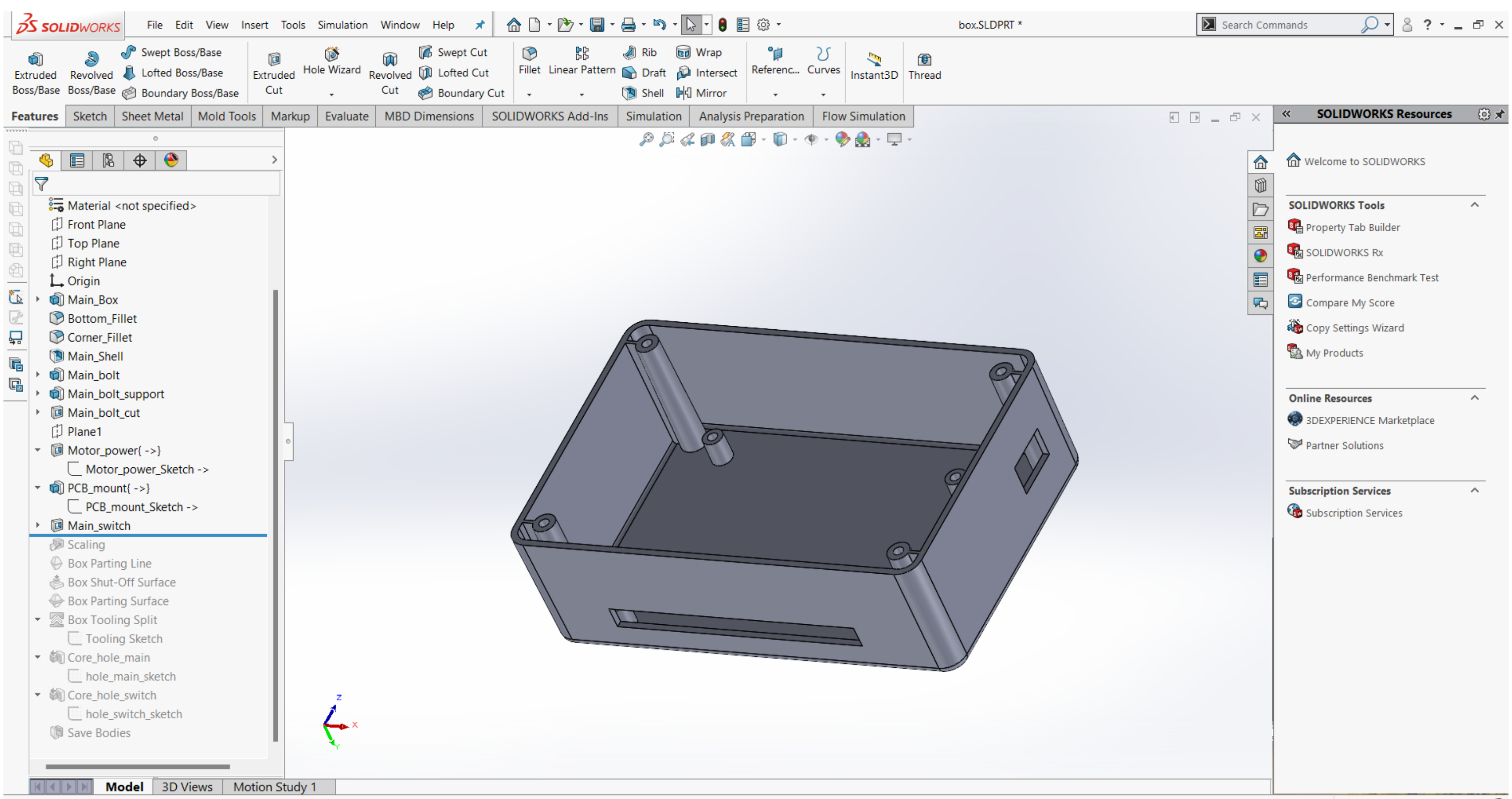

Figure 25: SolidWorks Design (Box part)

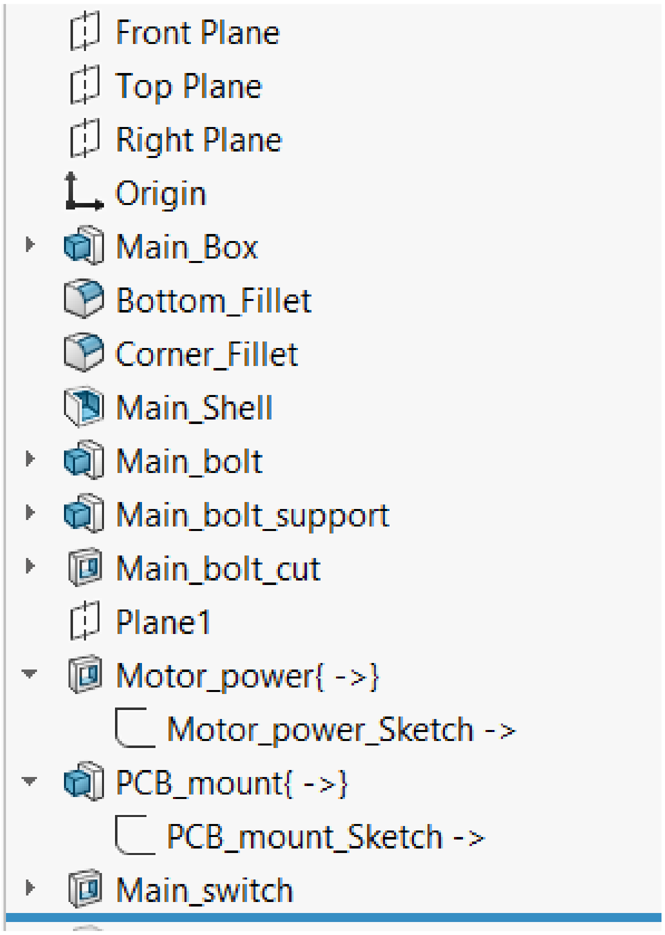

Figure 26: Expanded Design tree (Box part)

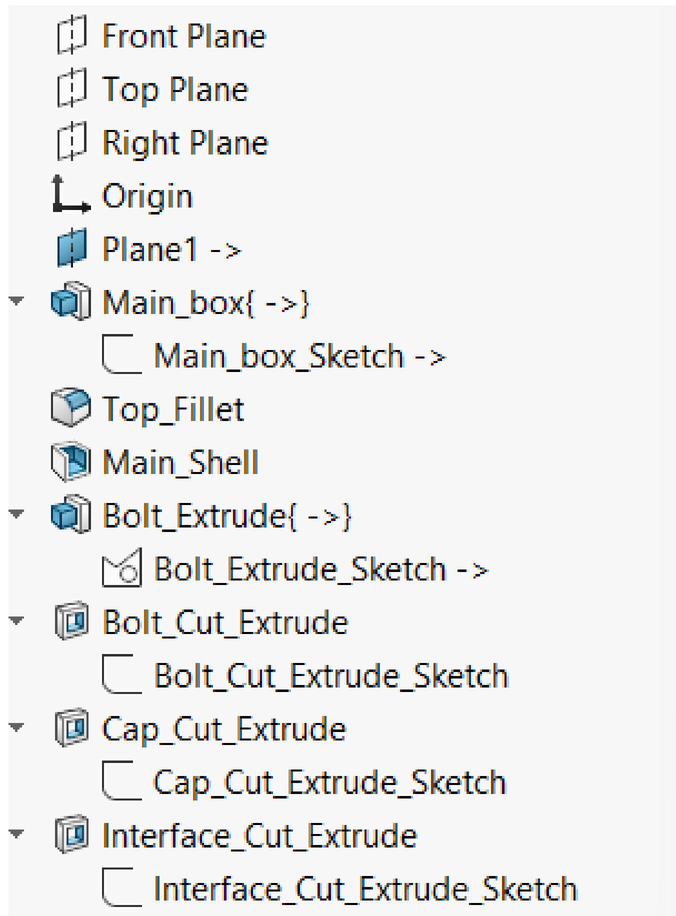

Figure 27: Expanded Design tree (Lid part)

11. References

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