Department of Electronic & Telecommunication Engineering

University of Moratuwa

Sri Lanka

Design of the Prototype
Zero gravity lifting device

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1 Introduction

This design of prototype report presents three innovative approaches for the enclosure of the Zero Gravity Arm/Lift Assist project and 3 conceptual designs for sensor technology and conceptual designs emphasizing their potential applications in lifting and manipulating materials within industrial settings.

These designs primarily focus on controlling the servo motor smoothly and sensing input data to enable precise lifting and tension maintenance of the cable according to the weight being lifted. Smooth control of the servo motor ensures precise movement and positioning of the lifting device, enhancing its efficiency and accuracy in industrial lifting operations. Additionally, incorporating sensors to detect input data such as weight allows for real-time adjustments in lifting operations, ensuring safe and reliable handling of materials within industrial settings. Given the critical role of these electronic components in the overall functionality of the lifting device, it is imperative to explore innovative conceptual designs that optimize control and sensing capabilities.

Furthermore, three conceptual designs are introduced for each aspect of the electronic components—servo motor control and sensor technology. This approach allows for thorough exploration of alternative solutions and ensures that a comprehensive range of possibilities is considered during the evaluation process. By presenting multiple conceptual designs, the project aims to identify the most effective and efficient solutions that address the specific requirements and challenges of the Zero Gravity Arm/Lift Assist project, ultimately contributing to its successful implementation in industrial settings.

The primary objective is to explore alternative solutions where conventional cranes or hoists may pose limitations. The next section outlines the evaluation process that scrutinizes the three conceptual designs, ultimately selecting the most optimal solution for implementation. The final section includes the enclosure design and schematic and PCB of the selected conceptual design.

2 User Requirements

- Purpose: The purpose of the Box Lifting Device is to provide users with a safe and user-friendly solution for lifting and manipulating heavy objects.
- Functional Requirements:
  - Payload Compatibility: The device must be capable of lifting various payload sizes and shapes within specified weight limits to accommodate diverse lifting tasks.
- Safety Requirements:
  - Overload Protection: The device should include mechanisms to detect and prevent overloading, ensuring safe operation and preventing damage to the device and payloads.
  - Emergency Stop: Include an emergency stop feature to immediately halt device operation in case of emergencies or unexpected situations, prioritizing user safety.
- Ease of Use Requirements:
  - Intuitive Controls: Design the control interface with intuitive controls and clear labeling to enable easy operation by users with minimal training or experience.
  - Ergonomic Design: Ensure the device is ergonomically designed with comfortable handles and grips, reducing user fatigue and enhancing user comfort during prolonged use.
  - Clear Feedback: Provide clear visual or auditory feedback to users to indicate the device's status and any relevant alerts or warnings during operation.

- Quick Setup: Facilitate quick and straightforward setup procedures for the device, including assembly, calibration, and configuration, to minimize downtime and enable users to start using the device promptly.

3 Mechanical conceptual designs

3.1 Design 1

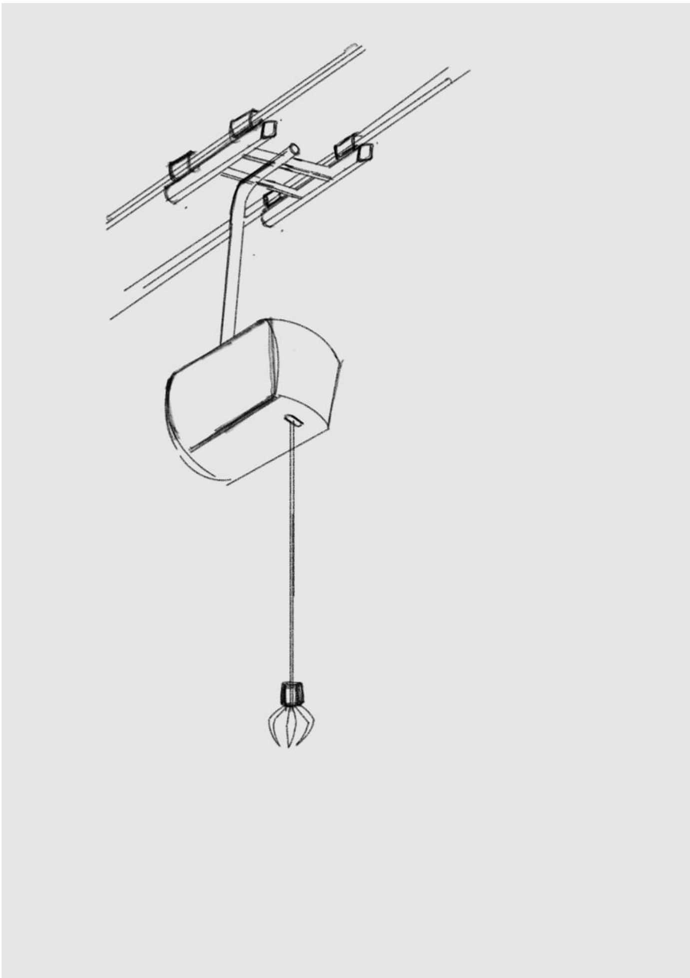


Figure 1: Design 1

The first conceptual design for a zero gravity lifting device tailored for industrial applications centers on a box housing a servo motor, facilitating movement along a robust steel bar track. Complementing this setup is a claw mechanism chosen as the primary grabbing tool. The design's degree of freedom is characterized by its ability to move along the axis.

3.2 Design 2

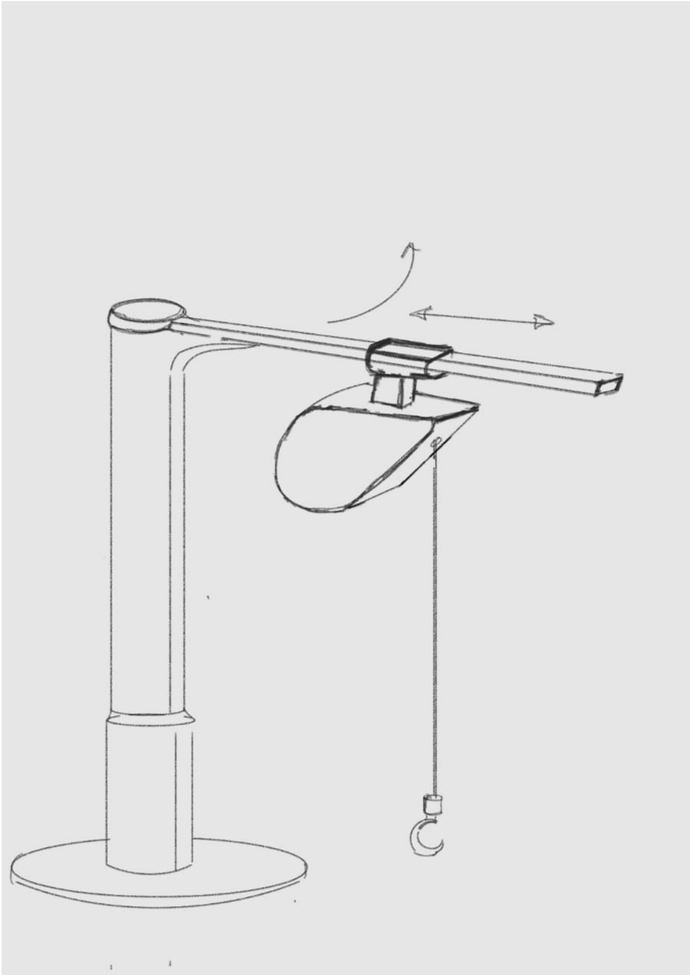


Figure 2: Design 2

For the second conceptual design of a zero gravity lifting device, we introduce a hook mechanism as the primary grabbing tool. This design incorporates a two-degree-of-freedom system, allowing the hook to rotate around a central column for approximately 270 degrees while also traversing along a horizontal bar track. This configuration offers enhanced flexibility and maneuverability, enabling the device to efficiently handle a wide range of lifting tasks within industrial environments. By combining the rotational capability of the hook with its horizontal movement along the bar track, this design provides increased versatility in accessing and lifting objects of varying shapes and sizes, thereby optimizing operational efficiency in industrial settings.

3.3 Design 3

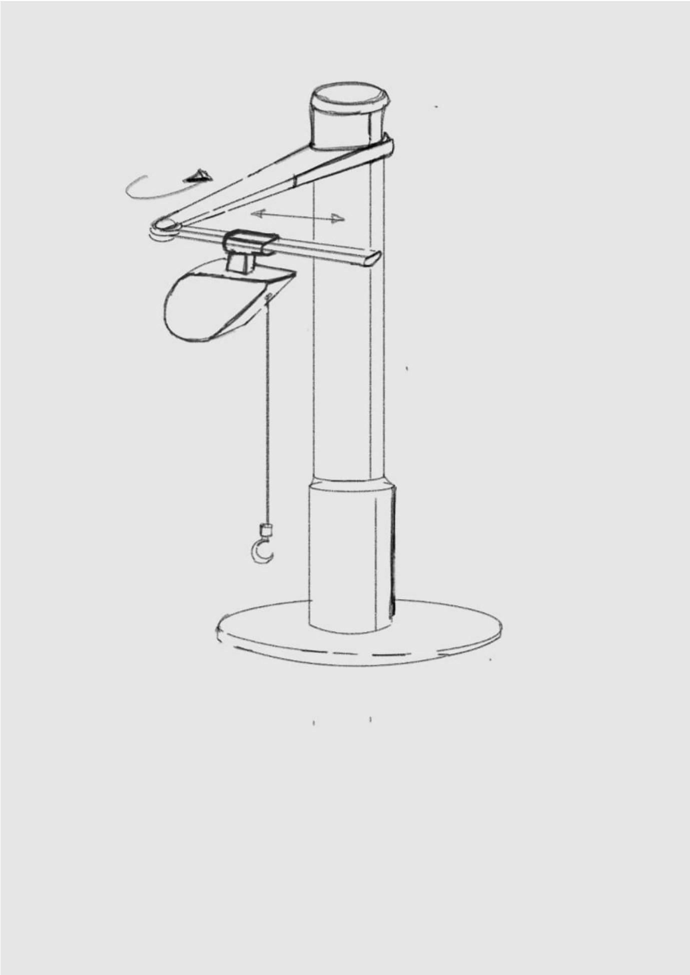


Figure 3: Design 3

In the third conceptual design iteration, we introduce a lifting device with a third degree of freedom to further enhance its capabilities for industrial applications. This additional degree of freedom adds complexity to the implementation process due to the need for intricate mechanisms and control systems.

The third degree of freedom in this design allows for vertical movement in addition to the horizontal traversal along the steel bar track and the rotational capability of the grabbing mechanism. This vertical movement enables the device to adjust its lifting position, accommodating varying heights of objects within the industrial environment.

3.4 Evaluation Criteria

To evaluate and select the optimal conceptual design for the zero gravity lifting device, we propose the following evaluation criteria:

- Maneuverability and Flexibility: Assess the degree to which each design facilitates movement in multiple directions within the industrial environment. Evaluate how effectively each design can navigate obstacles and reach various workstations or assembly points.
- Complexity and Implementation: Assess the complexity of implementing each design, considering factors such as manufacturing feasibility, assembly requirements, and maintenance considerations. Evaluate the potential challenges and resources required for constructing and deploying each design in real-world industrial settings.
- Operational Efficiency: Assess the overall efficiency and productivity gains offered by each design in performing lifting tasks within industrial environments. Consider factors such as speed of operation, ease of use, and compatibility with existing workflows or systems.
- Cost Effectiveness: Evaluate the cost-effectiveness of each design, considering factors such as initial investment, maintenance costs, and potential savings or productivity gains achieved through improved lifting capabilities and operational efficiency.
- Versatility and Adaptability: Assess the versatility and adaptability of each design in accommodating diverse lifting requirements and handling various types of objects commonly encountered in industrial settings. Consider the design's ability to accommodate future modifications or upgrades to meet evolving operational needs.

By thoroughly evaluating each conceptual design against these criteria, we can determine the optimal solution that best aligns with the requirements and priorities of industrial lifting applications.

3.5 Evaluation and Comparison of conceptual Designs

	Conceptual design 1	Conceptual design 2	Conceptual design 3
Maneuverability and Flexibility	5	8	9
Complexity and Implementation	8	8	5
Operational Efficiency	6	8	8
Cost-effectiveness	7	9	7
Versatility and Adaptability	7	8	7
Total	33	41	36

Table 1: Evaluation and Comparison of mechanical conceptual Designs

3.5.1 Selected Design- Design 2

Among the three conceptual designs evaluated based on maneuverability and flexibility, conceptual design 2 received the highest score of 8. This design showcased superior maneuverability and flexibility, attributed to its two-degree-of-freedom system allowing rotation around a column while moving along a horizontal bar track. This capability enhances the device's adaptability to navigate around obstacles and reach various workstations or assembly points within industrial environments.

Additionally, the rotational feature of the grabbing mechanism enables efficient handling of objects positioned at different angles, contributing to enhanced flexibility in lifting operations.

Furthermore, conceptual design 2 excelled in operational efficiency with a score of 8, reflecting its ability to optimize productivity in industrial lifting tasks. The integration of a two-degree-of-freedom system provides precise control over lifting operations, enabling the device to efficiently handle a wide range of object weights and sizes commonly encountered in industrial applications. Additionally, the design's versatility and adaptability contribute to its operational efficiency by accommodating diverse lifting requirements and seamlessly integrating with existing workflows or systems. As a result, conceptual design 2 emerges as the optimal choice, offering a balanced combination of maneuverability, efficiency, and versatility to meet the diverse needs of industrial lifting applications.

4 Design for controlling servo motor

Controlling servo motors effectively is crucial for the successful operation of the Zero Gravity Arm/Lift Assist project. Servo motors play a pivotal role in providing precise and controlled movement to the lifting device, allowing it to navigate through industrial environments with accuracy and efficiency. The ability to control servo motors smoothly directly impacts the device's maneuverability, positioning, and overall performance. Smooth control ensures that the lifting device can precisely lift, lower, and manipulate materials without causing damage to the surroundings or compromising safety.

This control process provides adjustable limit and gain control, enabling a more responsive and efficient movement of the load. At the core of this process is the utilization of user input to command the desired force, facilitated through a switch mechanism. The force command is then compared with the actual force measured by a force sensor, generating a force error signal indicative of any deviation. Subsequently, the dynamic limit module dynamically adjusts the output of the gain amplifier based on predetermined limit values, preventing abrupt changes in force command and ensuring stability during lifting operations. Furthermore, by dynamically limiting the velocity vector command output according to the weight of the load, the control process optimizes maneuverability, particularly for heavier loads where higher inertia necessitates careful handling. Ultimately, this approach aims to provide precise control over the servo motor, enhancing the overall efficiency and safety of the lifting device in industrial environments.

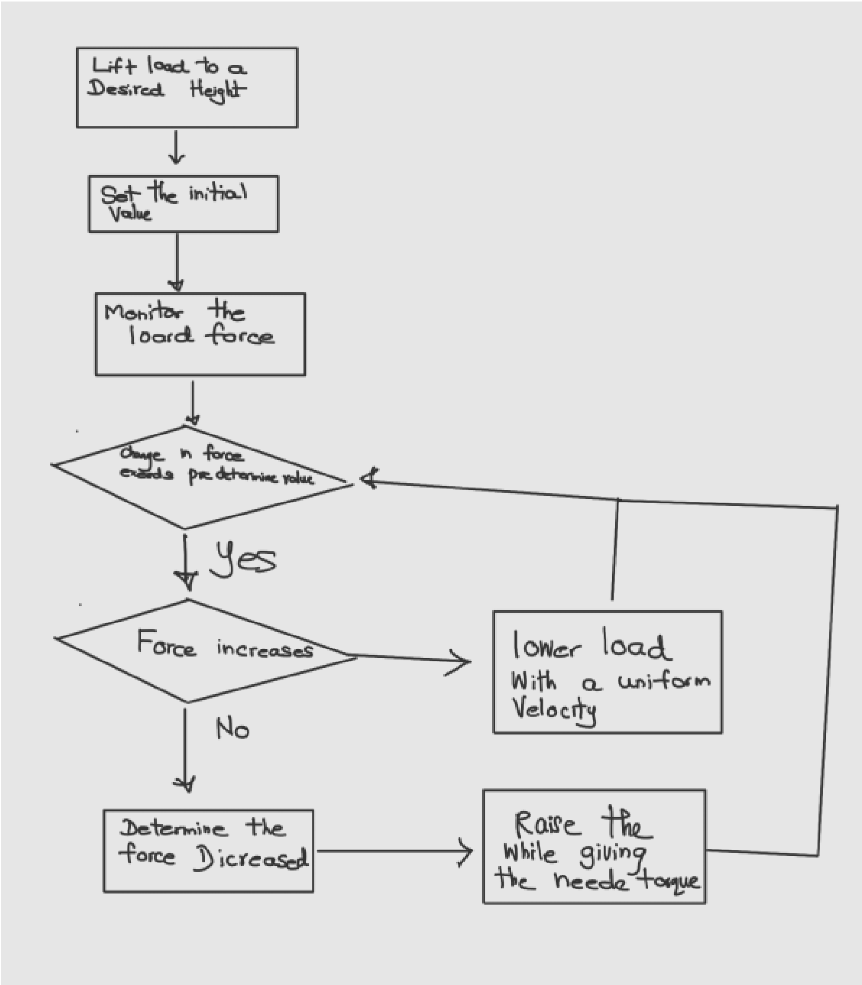


Figure 4: Design for controlling servo motor-Block diagram 1

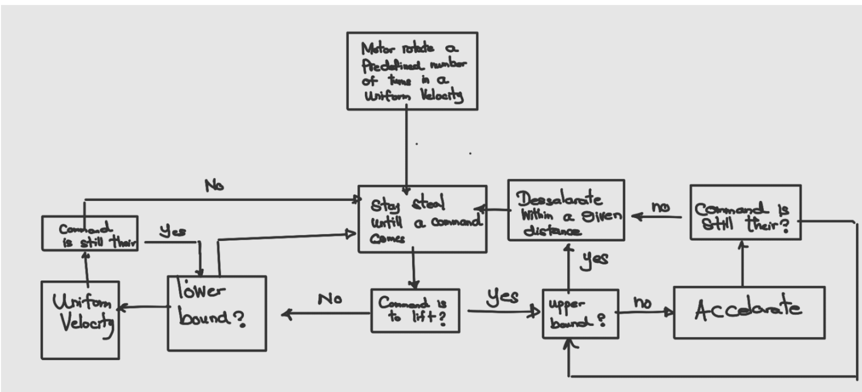


Figure 5: Design 1 for controlling servo motor velocity Block diagram 2

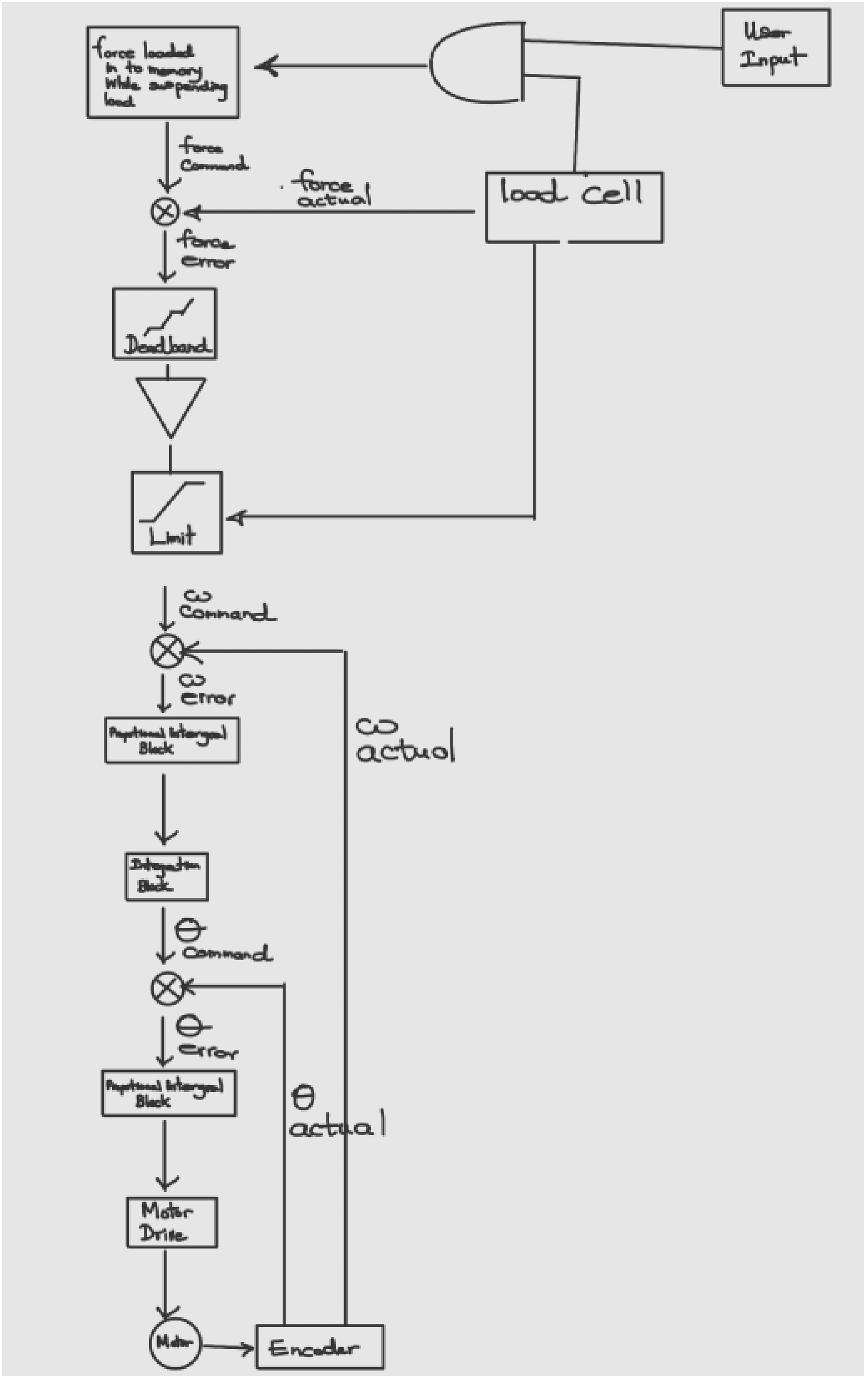


Figure 6: Design for controlling servo motor-Block diagram 3

5 Conceptual Designs for signal input

5.1 Design 1

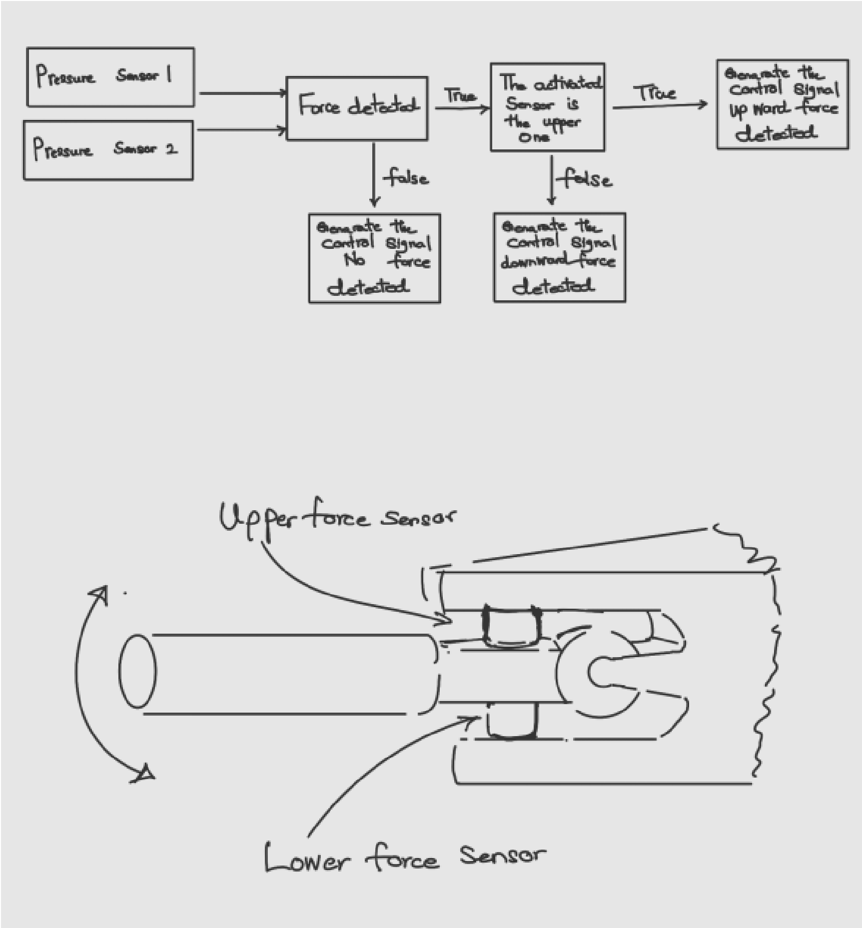


Figure 7: Design 1

This concept uses two pressure sensors at the users handle therefore has better sensitivity and ease of use. Since pressure sensors output an analog signal, we can design the system to have a varying velocity proportional to the force enforced on the box by the user giving a more realistic zero gravity feeling to the user. We can use more cost-effective pressure sensors since the range is at the lower side. Consequently, the load cells/pressure sensors won't have to deal with large forces therefore the design will be simpler. And more importantly the range of the load cell does not depend on the weight of the box, which will make the design more effective and simpler.

5.2 Design 2

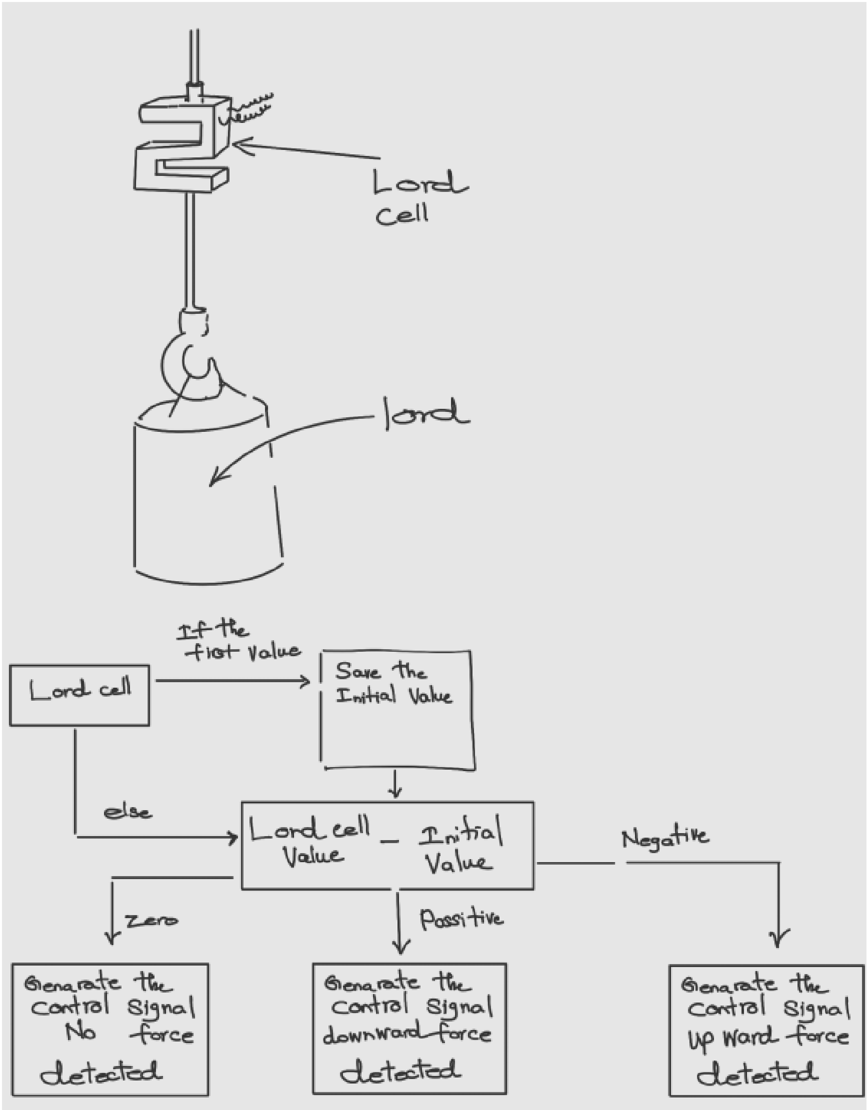


Figure 8: Design 2

This concept uses a load cell in between the cable and the box to be lifted. We will have to use more sophisticated load cells with a wider range and the range will depend on the weight of the box. Which will consequently make the design complex and arise difficulties in finding the optimal load cell. Since the load cells also output an analog signal, we can design the system to have a varying velocity proportional to the force enforced on the box by the user giving a more realistic zero gravity feeling to the user.

5.3 Design 3

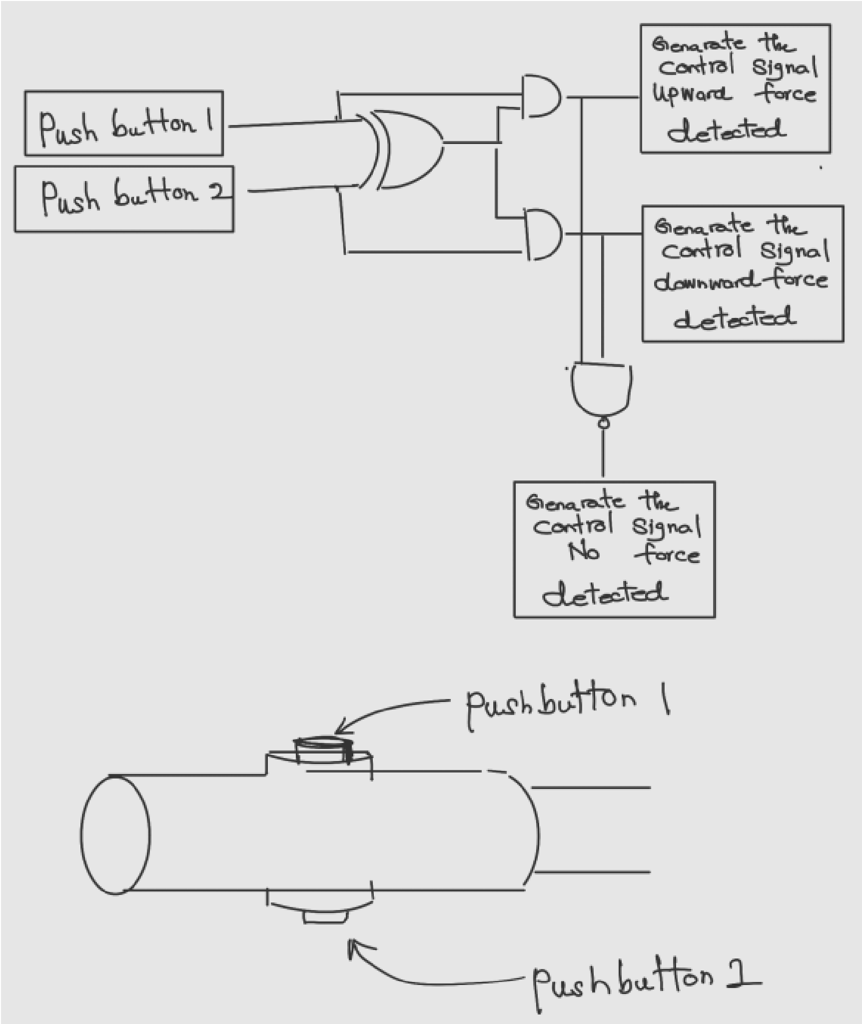


Figure 9: Design 2

This concept uses two push buttons at the users handle/ Since push buttons output a digital signal, we cannot design the system to have a varying velocity. Therefore, the realistic zero gravity feeling will be lost in this design. Rather it will give a machinery feeling to the user. This design will also be cost effective since the push buttons are not very expensive.

5.4 Evaluation Criteria

To evaluate and select the optimal conceptual design for the zero gravity lifting device, we propose the following evaluation criteria:

- Sensing Sensitivity: Evaluate the ability of the sensing mechanism to accurately detect subtle changes in force applied to the lifting device. Higher sensitivity allows for finer control and smoother operation, enhancing user experience and efficiency in lifting tasks.
- Realism of Feedback: Assess the extent to which the sensing mechanism can replicate the sensation of zero gravity or weightlessness, providing users with a realistic perception of the lifting process. Realistic feedback enhances user engagement and immersion in the task, contributing to improved performance and satisfaction.
- Compatibility with System Complexity: Consider the compatibility of the sensing mechanism with the overall complexity of the lifting device design. Evaluate whether the chosen sensing technology can be seamlessly integrated into the system architecture without significantly increasing complexity or compromising performance.
- Cost-Effectiveness: Analyze the cost-effectiveness of the sensing solution, taking into account factors such as sensor price, maintenance requirements, and long-term reliability. A cost-effective sensing mechanism offers value for money while meeting performance requirements.
- Ease of Implementation: Assess the ease of implementation and deployment of the sensing mechanism within the lifting device design. Consider factors such as sensor installation, calibration procedures, and compatibility with existing hardware and software components.
- Weight Dependency: Analyze how the sensing mechanism adjusts its response according to variations in the weight of the lifted object. Evaluate whether the sensing technology can effectively handle objects of different weights while maintaining sensitivity and realism in feedback.

5.5 Evaluation and Comparison of conceptual Designs

This criterion assesses the effectiveness of the sensing mechanism in providing accurate and realistic feedback to the user during lifting operations. It considers the sensitivity of the sensing system in detecting force variations and its ability to translate these variations into realistic motion responses.

	Conceptual design 1/Pressure sensors	Conceptual design/Push Button 2	Conceptual design 3/Load cell
Sensing Sensitivity	8	8	6
Realism of Feedback	8	6	6
Compatibility with System Complexity	9	8	6
Cost-effectiveness	8	9	7
Ease of Implementation	8	8	7
Dependency on weight	9	9	5
Total	50	48	37

Table 2: Evaluation and Comparison of sensing mechanism conceptual Designs

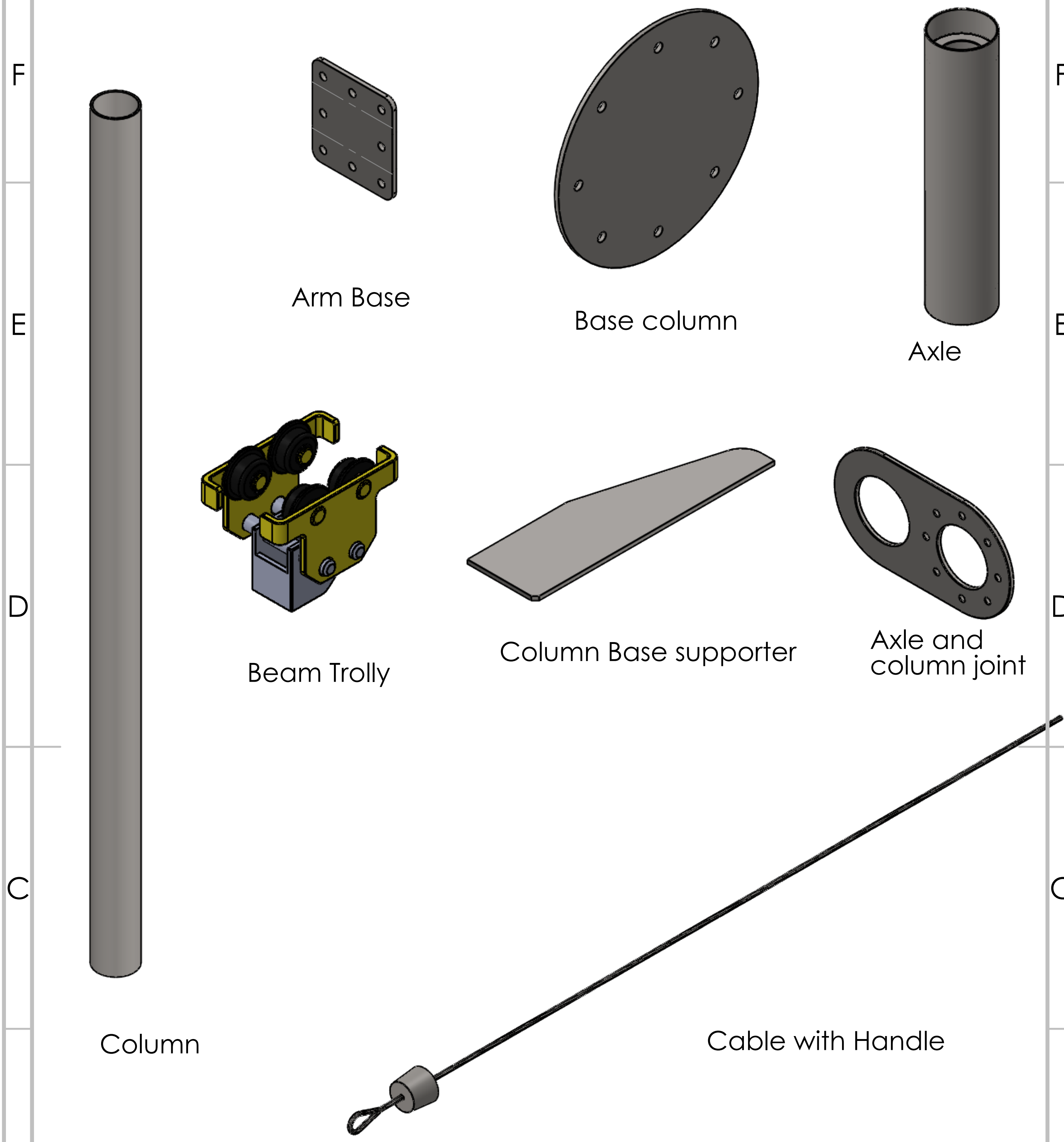
5.5.1 Selected Design-Design 1

Based on the evaluation and comparison of the three conceptual designs for sensing mechanisms, Conceptual Design 1 utilizing pressure sensors emerges as the most optimal choice for the Zero Gravity Arm/Lift Assist project. This design scored highest in Sensing Sensitivity and Realism of Feedback, indicating superior performance in accurately detecting force variations and providing realistic feedback to the user during lifting operations. Additionally, it achieved commendable scores in Compatibility with System Complexity, Cost-effectiveness, and Ease of Implementation, showcasing its suitability for seamless integration into the overall system architecture while offering value for money and ease of deployment. By incorporating pressure sensors at the user's handle, this design ensures better sensitivity, ease of use, and a more realistic zero gravity feeling for the user, enhancing overall user experience and operational efficiency. Therefore, Conceptual Design 1 stands out as the optimal choice, promising enhanced performance, realism, and user satisfaction in zero gravity lifting operations within industrial settings.

6 Enclosure Design of the prototype

The enclosure design of the prototype for the Zero Gravity Arm/Lift Assist project is pivotal in ensuring the functionality, safety, and durability of the device within industrial settings. Crafted from high-strength materials such as reinforced plastics or metals, the enclosure provides robust protection to internal components against environmental elements such as dust, moisture, and mechanical stresses. To enhance structural integrity, beams within the enclosure, suitable for a height of 2 meters, are typically fabricated from materials like aluminum or steel, chosen for their strength-to-weight ratio and resistance to deformation under load.

A meticulous approach is taken in the design process, where numerous part files are created for individual components before assembly using software like SolidWorks. This ensures precise fitment and compatibility among parts, contributing to the overall reliability of the enclosure. Additionally, SolidWorks is utilized to create the enclosure, ensuring accurate modeling and integration of all components.



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	NAME	SIGNATURE	DATE
DRAWN	Group Zero Gravity		1/4/2024
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

Part Files

DWG NO.

Zero gravity

A4

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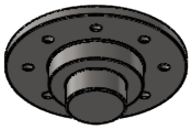
SHEET 1 OF 3



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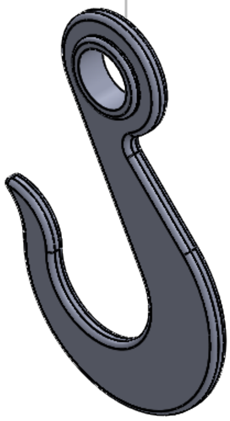

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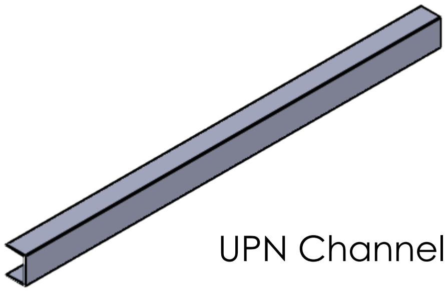
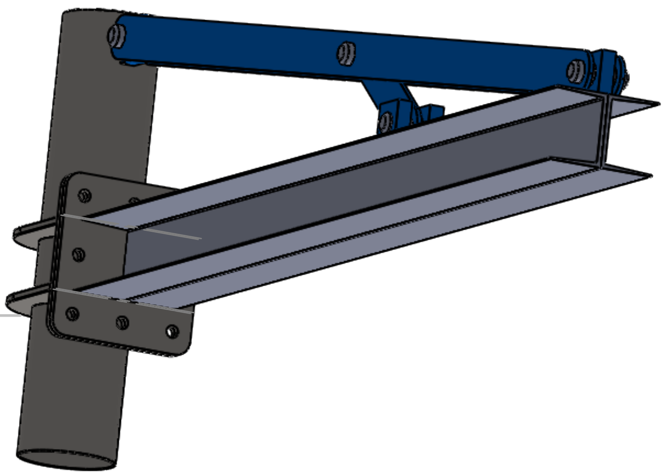
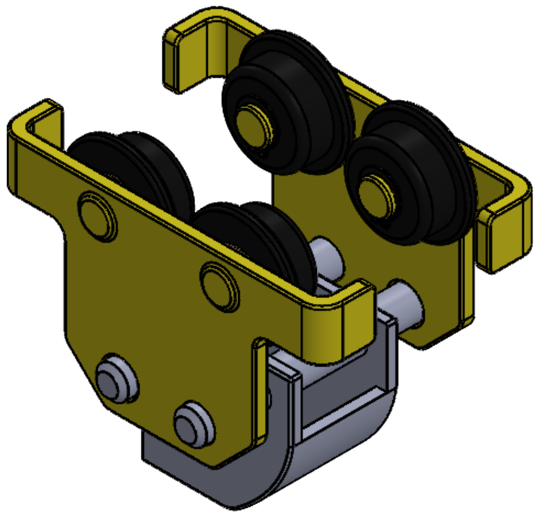


UPN Channel

Sub Assemblies



Axle assembly



Beam Trolly

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CHK'D				
APPV'D				
MFG				
Q.A				

TITLE:

Part Files and Sub assembly

MATERIAL:

DWG NO.

Zero gravity

A4

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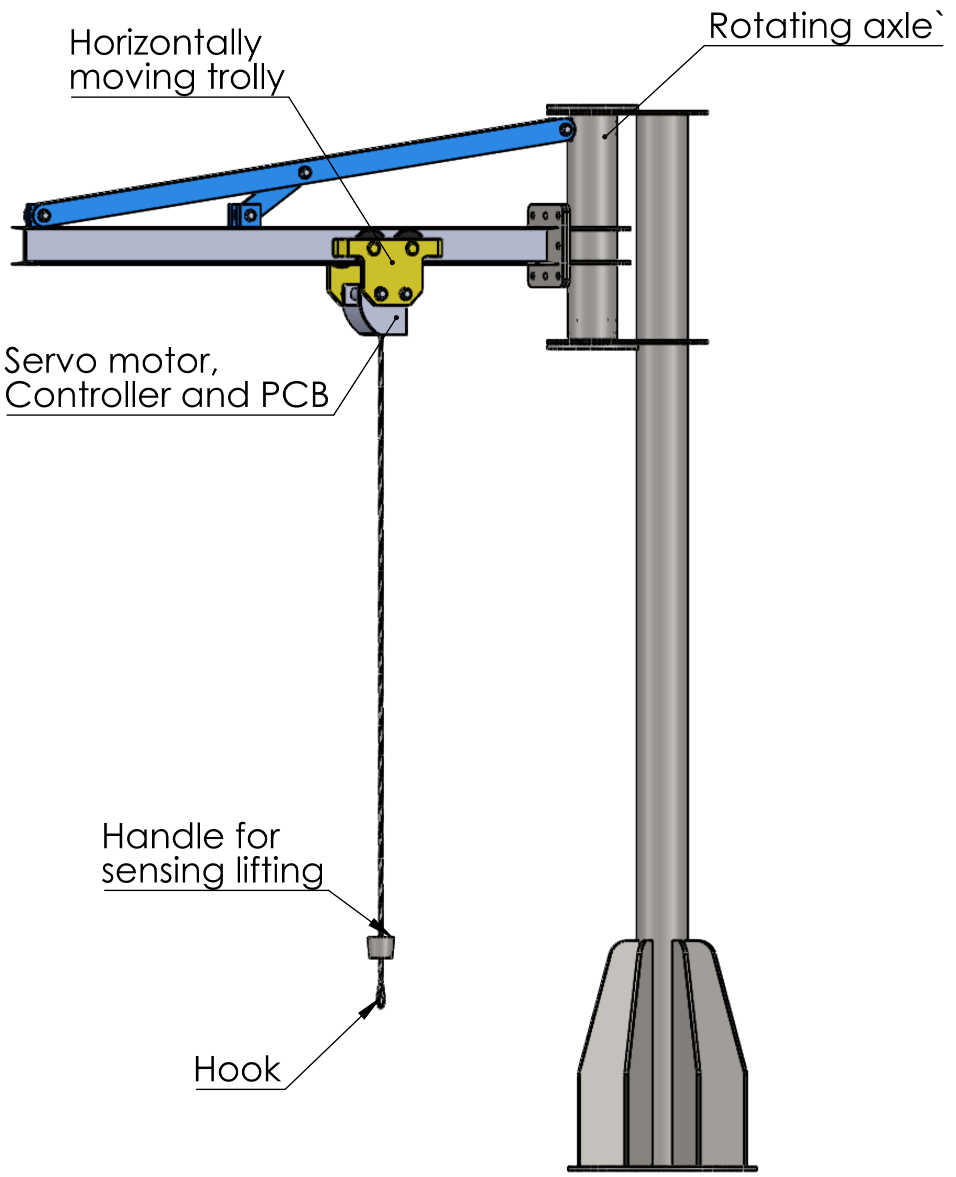
SHEET 2 OF 3



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CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE: Assembly- Zero gravity

DWG NO. Zero gravity

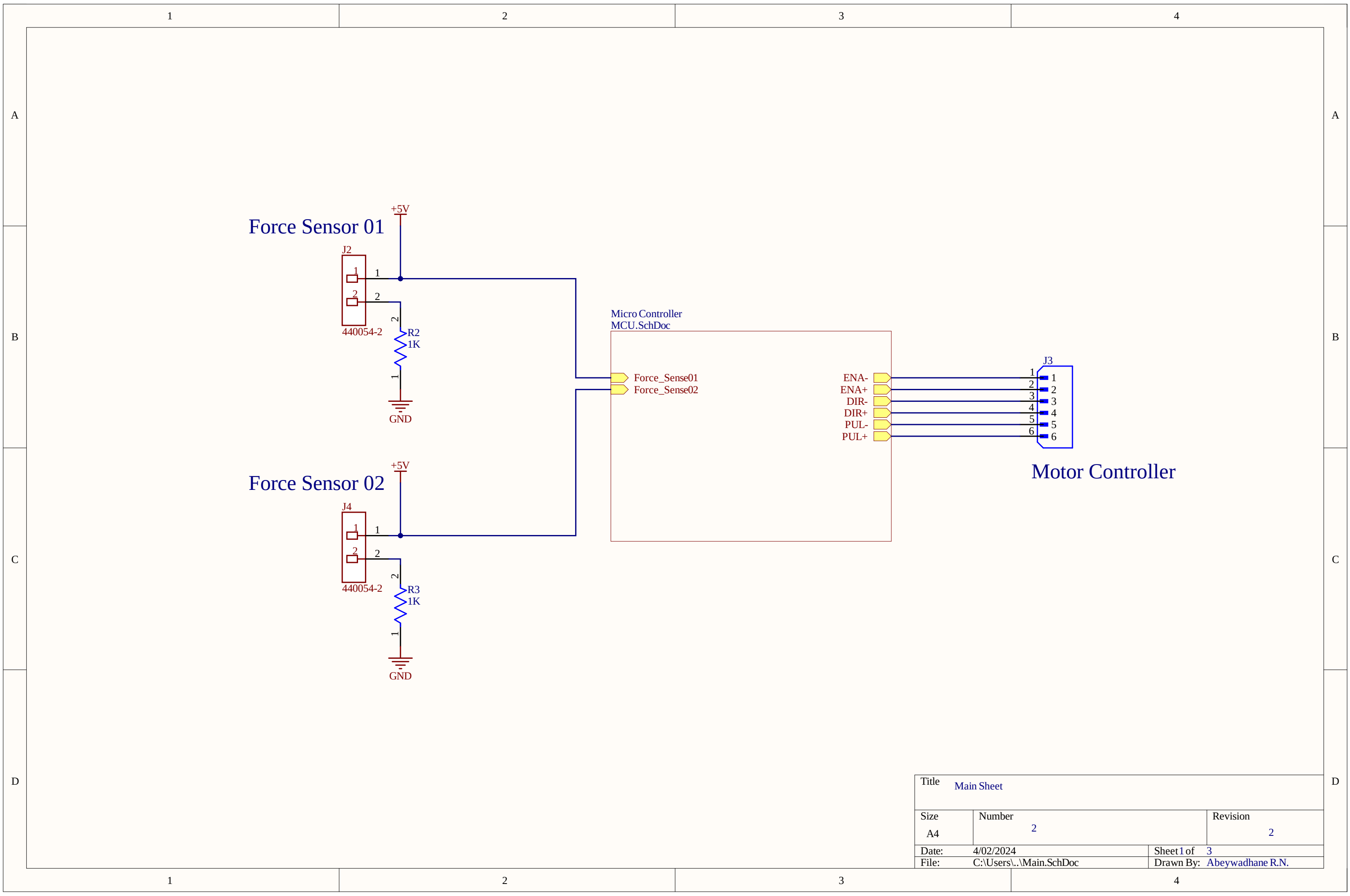
A4

SCALE:1:50

SHEET 3 OF 3

7 Schematic and PCB design of the prototype

The Box Lifting Device utilizes an Atemega328P chip as its microcontroller. To power up the stepper motor, a 12V AC to DC adapter is used, which is then stepped down to 5V using a buck converter to supply the necessary voltage to the Atmega chip. Additionally, two pressure sensors are integrated with the microcontroller to detect user actions such as lifting and releasing the box. Based on these inputs and other relevant parameters, appropriate control signals are generated and sent to the TB6600 stepper motor controller for regulating the NEMA23 stepper motor.



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R2
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GND
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R3
1K
GND
Micro Controller
MCU.SchDoc
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Force_Sense02
ENA-
ENA+
DIR-
DIR+
PUL-
PUL+
J3
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3
4
5
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Revision 2
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Sheet 1 of 3
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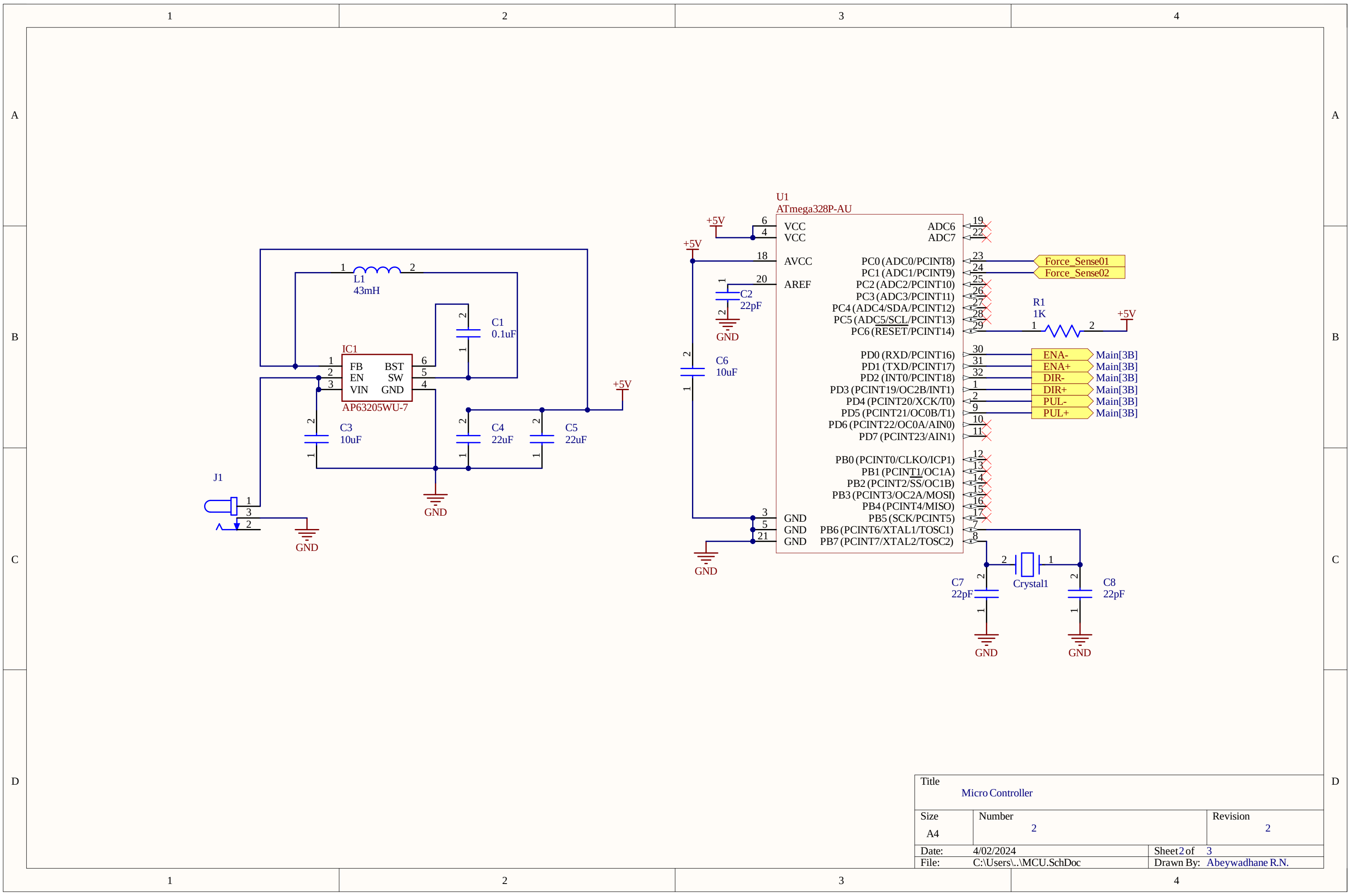
Drawn By: Abeywadhane R.N.



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AVCC
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ADC7
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PC4 (ADC4/SDA/PCINT12)
PC5 (ADC5/SCL/PCINT13)
PC6 (RESET/PCINT14)
PD0 (RXD/PCINT16)
PD1 (TXD/PCINT17)
PD2 (INT0/PCINT18)
PD3 (PCINT19/OC2B/INT1)
PD4 (PCINT20/XCK/T0)
PD5 (PCINT21/OC0B/T1)
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PD7 (PCINT23/AIN1)
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PB4 (PCINT4/MISO)
PB5 (SCK/PCINT5)
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Sheet 2 of 3
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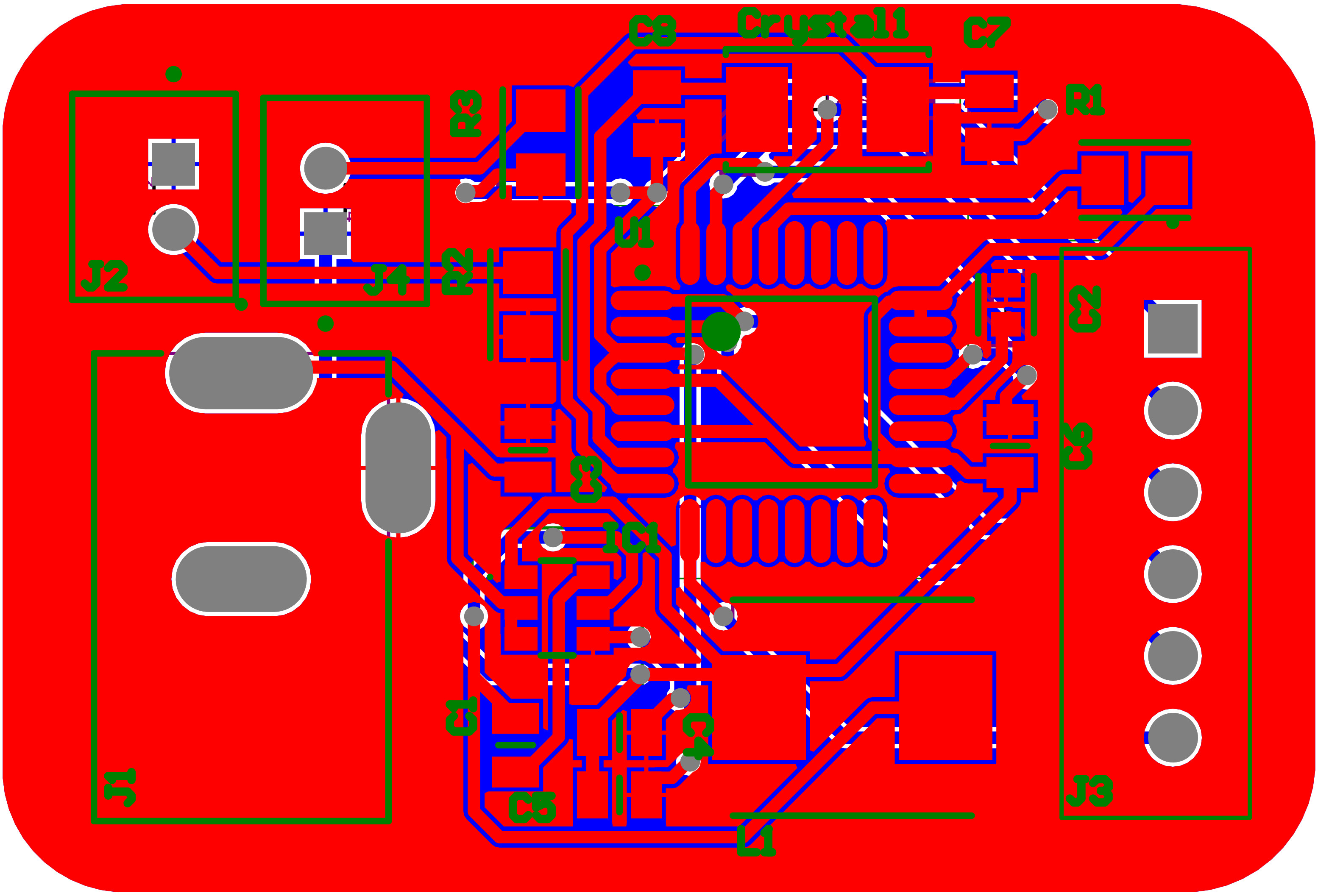
Drawn By: Abeywadhane R.N.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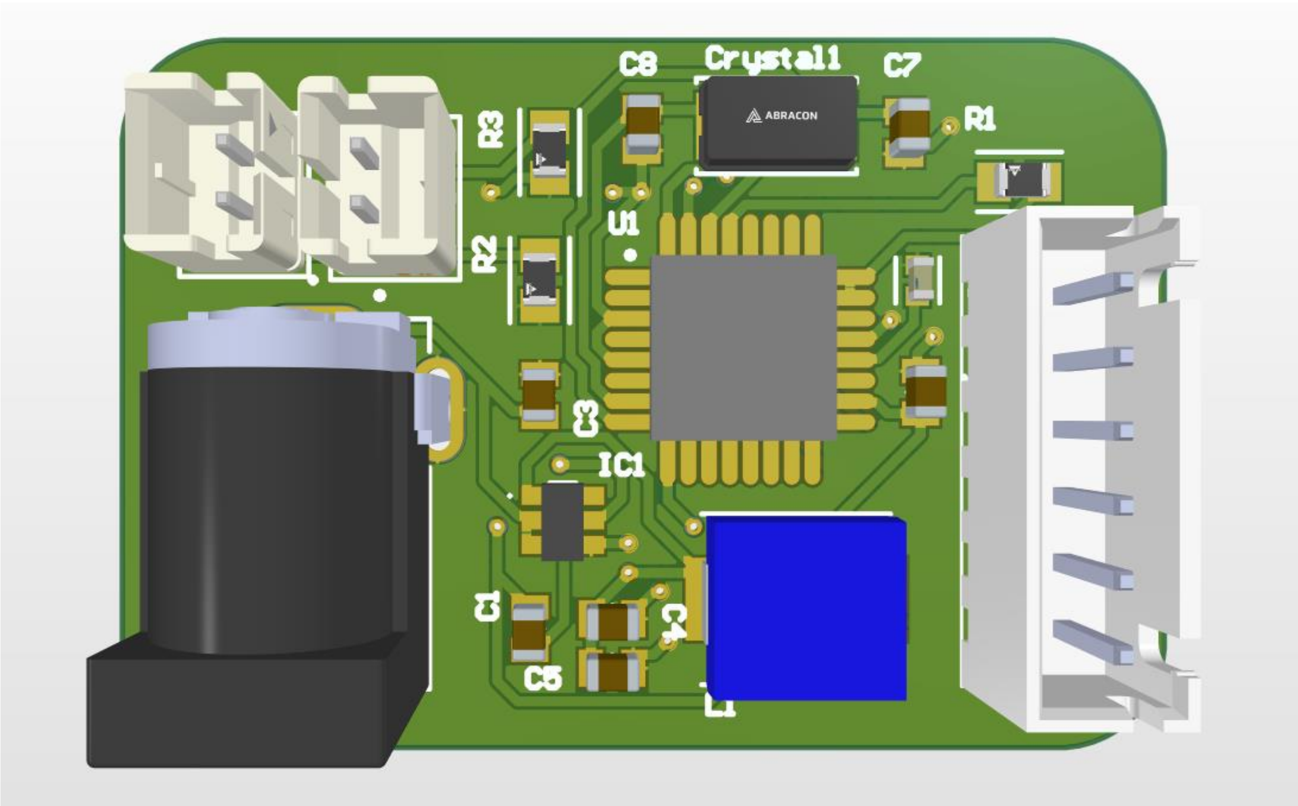

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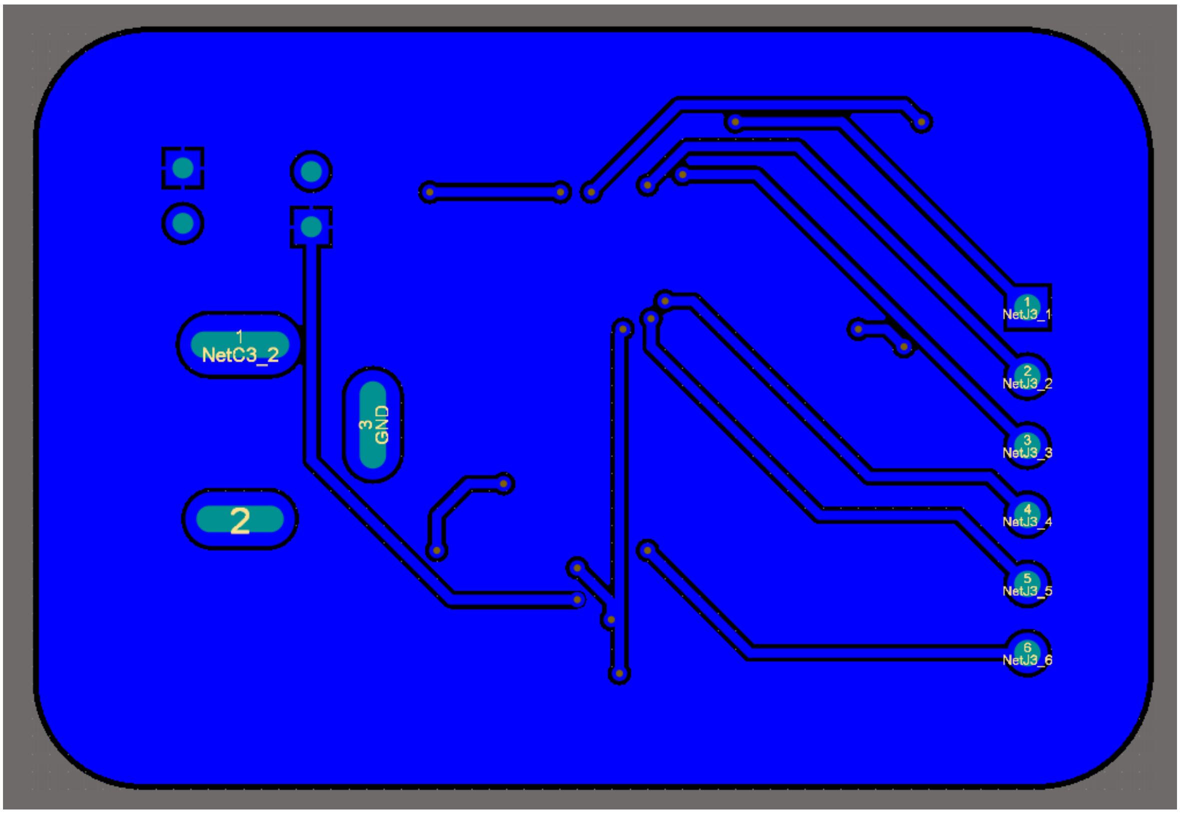
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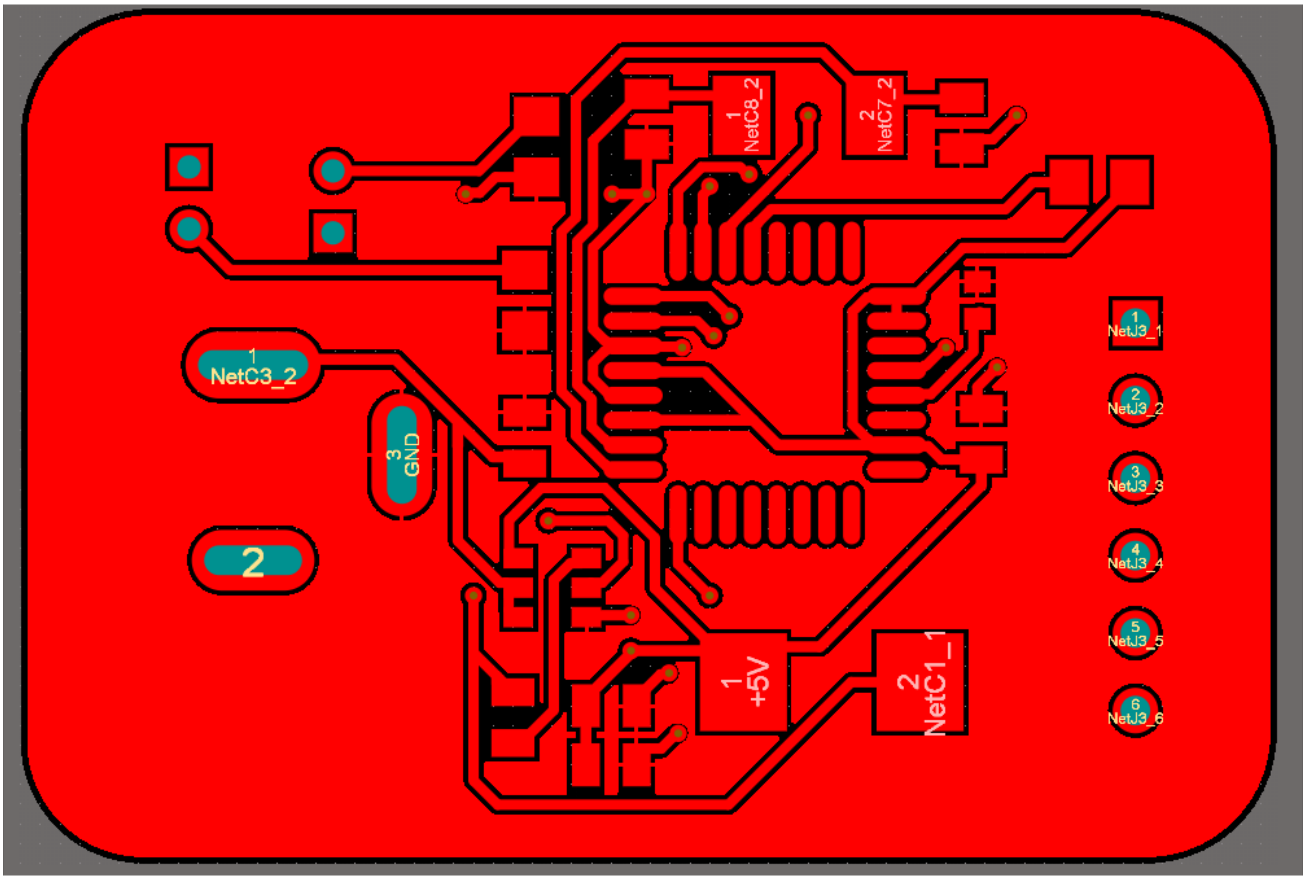

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