



Department of Electronic & Telecommunication Engineering

University of Moratuwa
Sri Lanka

Design Methodology Zero gravity lifting device

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1 Review Progress

1 Introduction

This report provides an overview of the progress made in the development of the **Zero Gravity Arm/Lift Assist project**, focusing on the application of innovative technologies to lift and manipulate materials in an industrial environment. The project aims to address challenges where traditional cranes or hoists may be impractical, offering a versatile solution with the Zero Gravity Part Manipulator Arm. Information presented here is derived from a comprehensive review of existing technologies, methodologies, and insights from reputable sources such as research articles, product documentation, and industry videos.

2 Review Progress

We conducted a thorough analysis of how various companies and universities are approaching the task of lifting and manipulating objects in zero gravity using a specialized lifter or arm. Our goal was to understand the current state of technology and gather insights into the methods and innovations being employed. We relied on sources such as YouTube videos, product brochures, and research articles to inform our understanding. This research serves as the foundation for our proposed project, helping us plan and design based on the latest advancements in zero-gravity lifting technology.

2.1 Zero Gravity Lifting Technologies: Manufacturer Innovations

In the review progress section, a dedicated subtopic focuses on exploring the cutting-edge zero gravity lifting technologies introduced by manufacturers. This subtopic delves into the unique features, advancements, and applications of zero-gravity lifting systems, with a specific emphasis on innovations brought forth by industry-leading manufacturers.

2.1.1 Gorbelt Easy Arm Intelligent Lifting Arm: Ergonomic Partners

The Gorbelt Easy Arm Articulating Smart Jib Cranes incorporate key technologies for efficient lifting.



Figure 1: Gorbelt Easy Arm Intelligent Lifting Arm

- G-Force Intelligent Hoist:
Integrates strength, precision, and speed with G-Force lifting technology.
- Flexible Installation:
Free-standing and under-hung options with various capacities and spans.

- Unmatched Precision:
Operates at speeds less than 1 fpm with two pivot points for delicate object handling.
 - Handle Configurations:
Various handle options for user flexibility, including force-sensing handles.
 - Cable Management:
G360 swivel assembly collector prevents cable tangling, ensuring smooth operation.
 - Zero-Gravity Float Mode:
Allows precise load manipulation using hands, functioning as a true zero-gravity lifter.
- * Webpage: <https://www.ergonomicpartners.com/gorbel-g-force>
 - * YouTube: Automotive Lift Assist with Zero Gravity Arm
 - Link: <https://www.youtube.com/watch?v=AF6rBc1sEww>

2.1.2 Zero-Gravity suspended radiation protection system : Biotronik

The Zero-Gravity® Suspended Radiation Protection System addresses the increasing challenges faced by interventionists during fluoroscopic procedures. With a focus on reducing cumulative radiation doses and orthopedic strain, this innovative system eliminates the weight burden for operators, enhancing radiation protection without compromising mobility.

- * Adaptable Configurations:
 - Floor Unit: Repositionable for various procedures and easily stored.
 - Monorail: Suspended from a ceiling-mounted rail, offering flexibility in room configurations and patient access.
 - Hinged Swing Arm: Ideal when ceiling-mounted equipment restricts rail use, with single fixation point and stowable shield.
 - Monorail Hinged Swing Arm: Combines advantages of Hinged Swing Arm and Monorail, providing maximum patient access.

After establishing contact with Biotronix, we successfully obtained their product brochure for the Zero-Gravity suspended radiation protection system. This valuable resource provided additional insights into the features, specifications, and applications of their innovative product, enhancing our understanding and contributing to the comprehensive analysis of radiation protection solutions in medical environments.

- * Webpage: <https://www.biotronik.com/en-sea/products/zero-gravity>

2.1.3 Intelligent Devices for Handling INDEVA of the Liftronic Series featuring advanced electronic control technology

The Liftronic INDEVA Intelligent Devices for Handling incorporate several advanced technologies to enhance their performance and user experience. Here are the key technologies used:

- Auto-weight sensing and auto-balancing capabilities



Figure 2: Zero-Gravity suspended radiation protection system

- Responsive and precise electronic control
- Ergonomic design for effortless handling
- Remote troubleshooting through App-Indeva
- Industry 4.0 interconnectivity
- Efficient auto diagnostic system
- Utilization of electronic control and automation
- Human extender technology for enhanced capabilities
- Tailored for speed, fluid movement, and precise load positioning



Figure 3: The Liftronic

* Webpage: <https://www.indevagroup.com/industrial-manipulators/>

* Video: <https://youtu.be/GRpa-XghiB4>

2.2 Evaluating Servo Motor Pros and Cons

Our investigation within the realm of zero gravity lifting technologies included a focused examination of the advantages and disadvantages associated with the available servo motors. This analysis aims to provide a comprehensive understanding of the positive attributes and limitations of servo motors, facilitating informed decision-making in their application within zero gravity lifting systems. In the review progress section, a dedicated subtopic focuses on exploring the cutting-edge zero gravity lifting technologies introduced by manufacturers. This subtopic delves into the unique features, advancements, and applications of zero-gravity lifting systems, with a specific emphasis on innovations brought forth by industry-leading manufacturers.

3 Plan next steps

Having laid the foundation with an insightful exploration into existing technologies and methodologies for zero gravity lifting, our next steps involve a strategic plan to delve deeper into the intricacies of this cutting-edge field. We are currently studying available servo motors, assessing their pros and cons.

1. Technology Research:

Conduct in-depth research on existing zero gravity lifting technologies, considering advancements, industry standards, and manufacturer specifications.

2. Identification of Optimal Technologies:

Define criteria for evaluating zero gravity lifting technologies, focusing on factors such as efficiency, precision, adaptability, and safety.

3. Prototype Development:

Initiate the development of a prototype based on the chosen zero gravity lifting model, incorporating the fine-tuned algorithms and mechanisms necessary for operation in a weightless environment.

4. Testing and Validation:

Conduct rigorous testing and validation procedures to ensure the reliability and performance of the zero gravity lifting system under various conditions.

5. Safety Protocols Implementation:

Prioritize the integration of safety protocols and fail-safe mechanisms to guarantee secure and efficient operation in zero gravity environments.

6. Documentation and Reporting:

Document the entire process, including model selection, fine-tuning, and integration steps, providing a comprehensive report for future reference and continuous improvement.

4 Stakeholder analysis

Understanding the interests and influence levels of these stakeholders is crucial for effective project management and successful implementation of zero gravity lifting technologies.

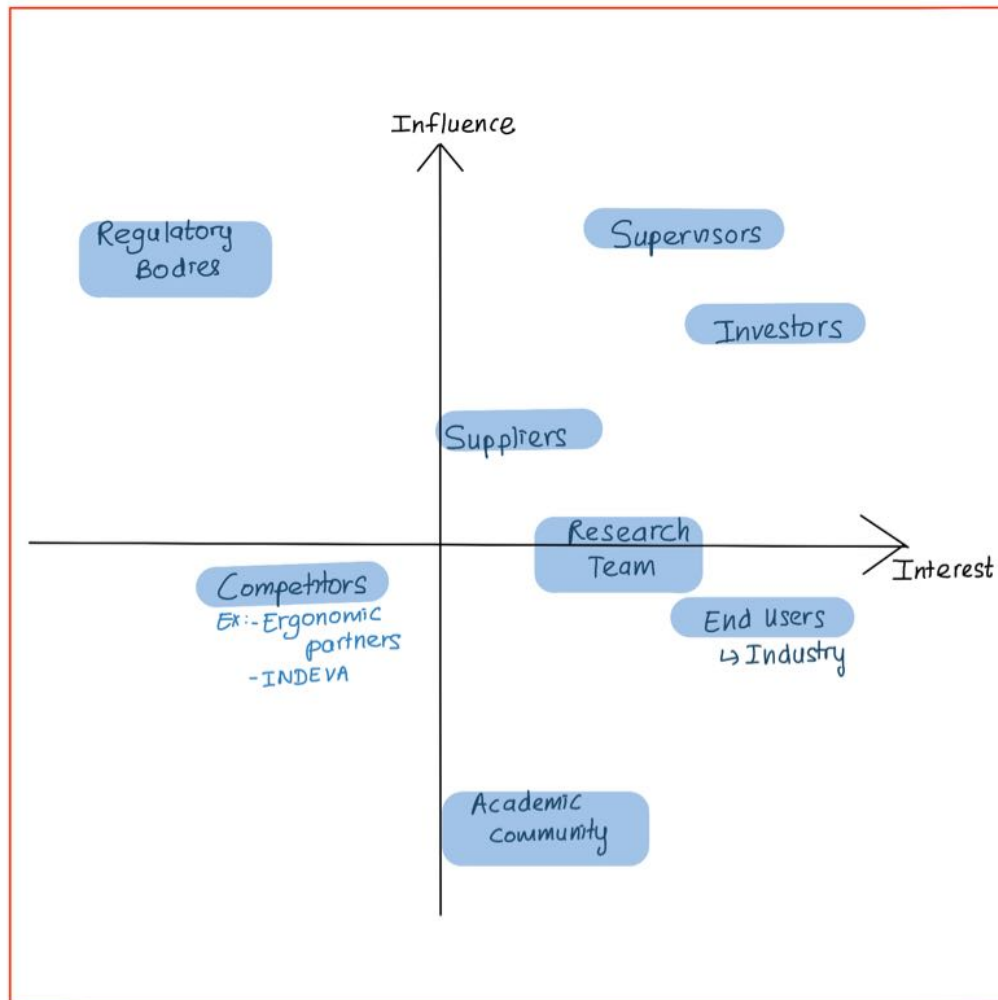


Figure 4: Stakeholder Map

5 Conclusion

In conclusion, our exploration into zero gravity lifting technologies has been methodical and insightful. We've delved into advanced solutions, established criteria for evaluation, and initiated the development of a prototype. The stakeholder analysis underlines the importance of collaboration for project success. As we move forward, integrating safety measures and documenting each step is key to building a strong foundation. The focus on a prototype represents a practical step toward realizing a functional zero gravity lifting system. Our decision-making process prioritizes efficiency, adaptability, and precision. This journey is not just about technology; it's a step into a future where zero gravity

lifting can transform from idea to reality, revolutionizing industrial applications. Moving forward, our commitment to innovation, safety, and collaboration will drive us towards unprecedented advancements in zero gravity lifting.

2 Conceptual Design

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

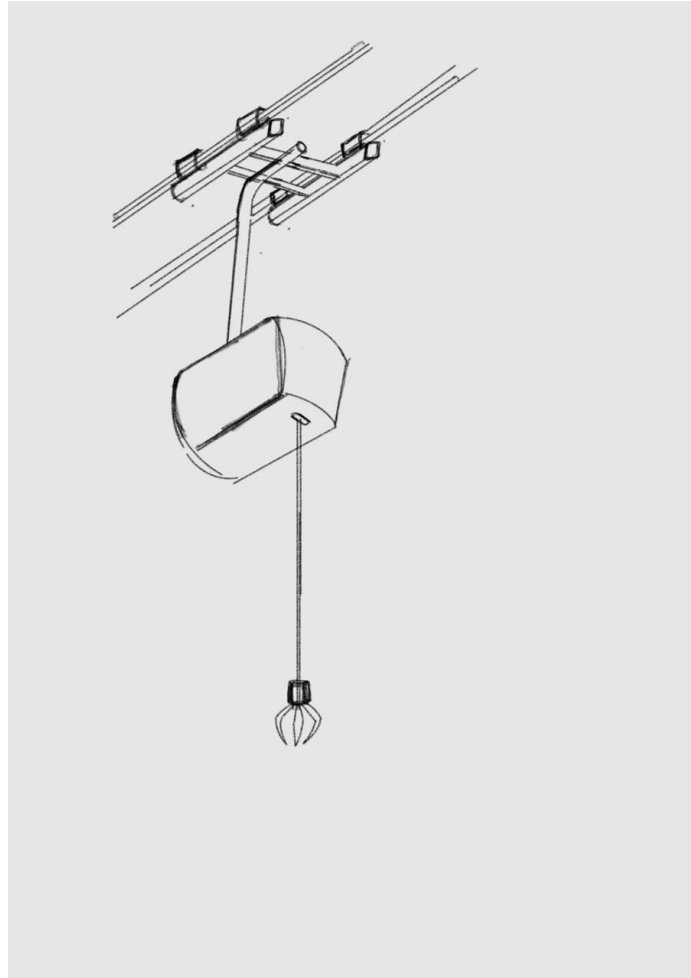


Figure 1: Design 1

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

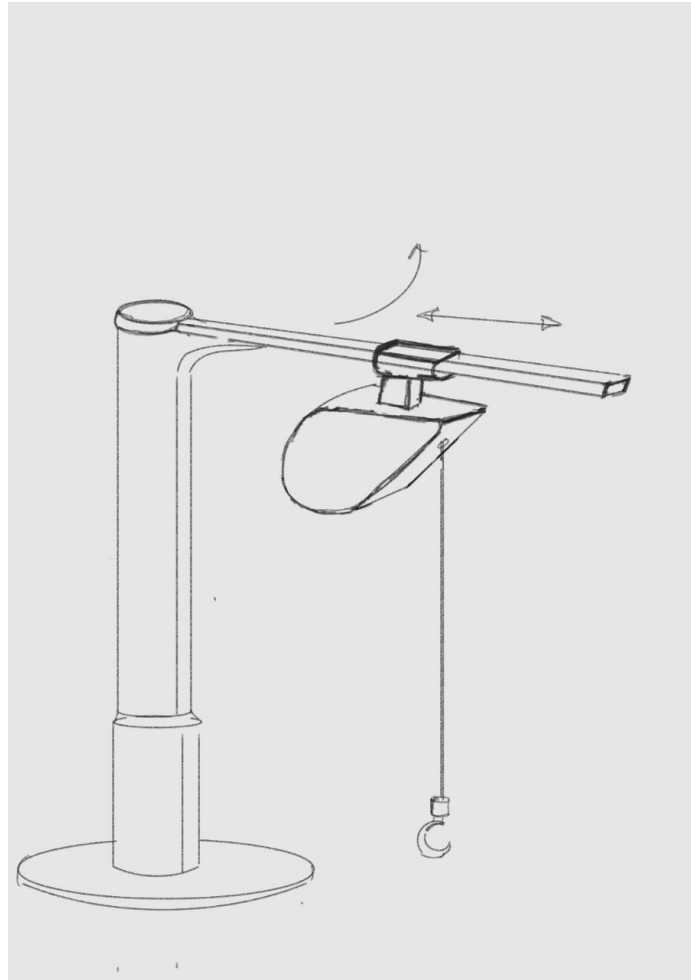


Figure 2: Design 2

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

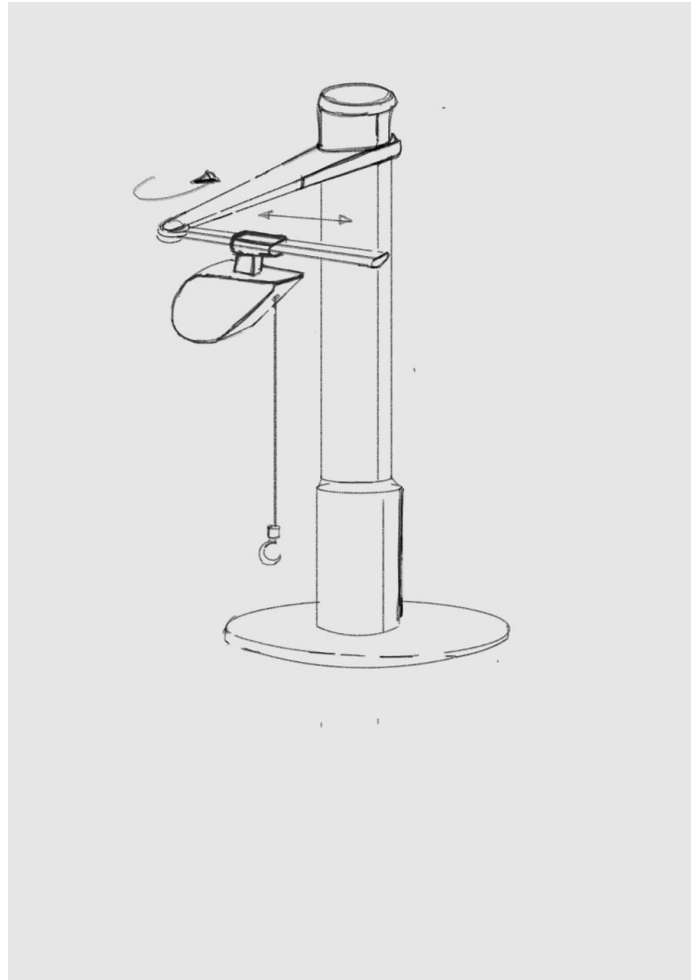


Figure 3: Design 3

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.

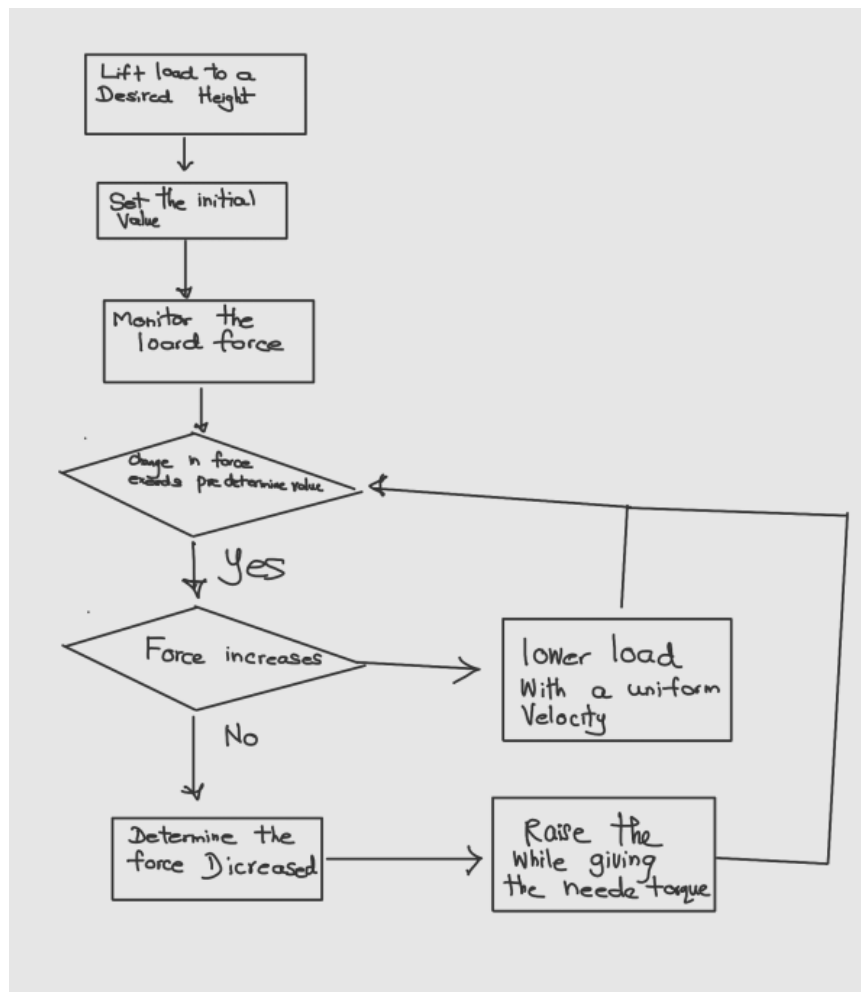


Figure 4: Design for controlling servo motor-Block diagram 1

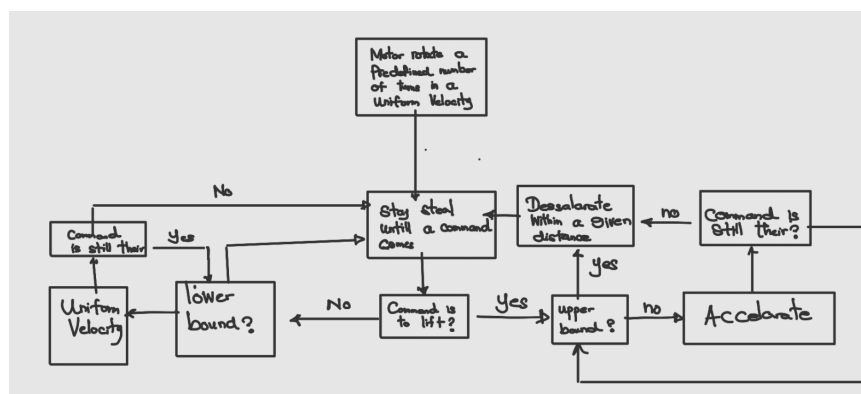


Figure 5: Design 1 for controlling servo motor velocity Block diagram 2

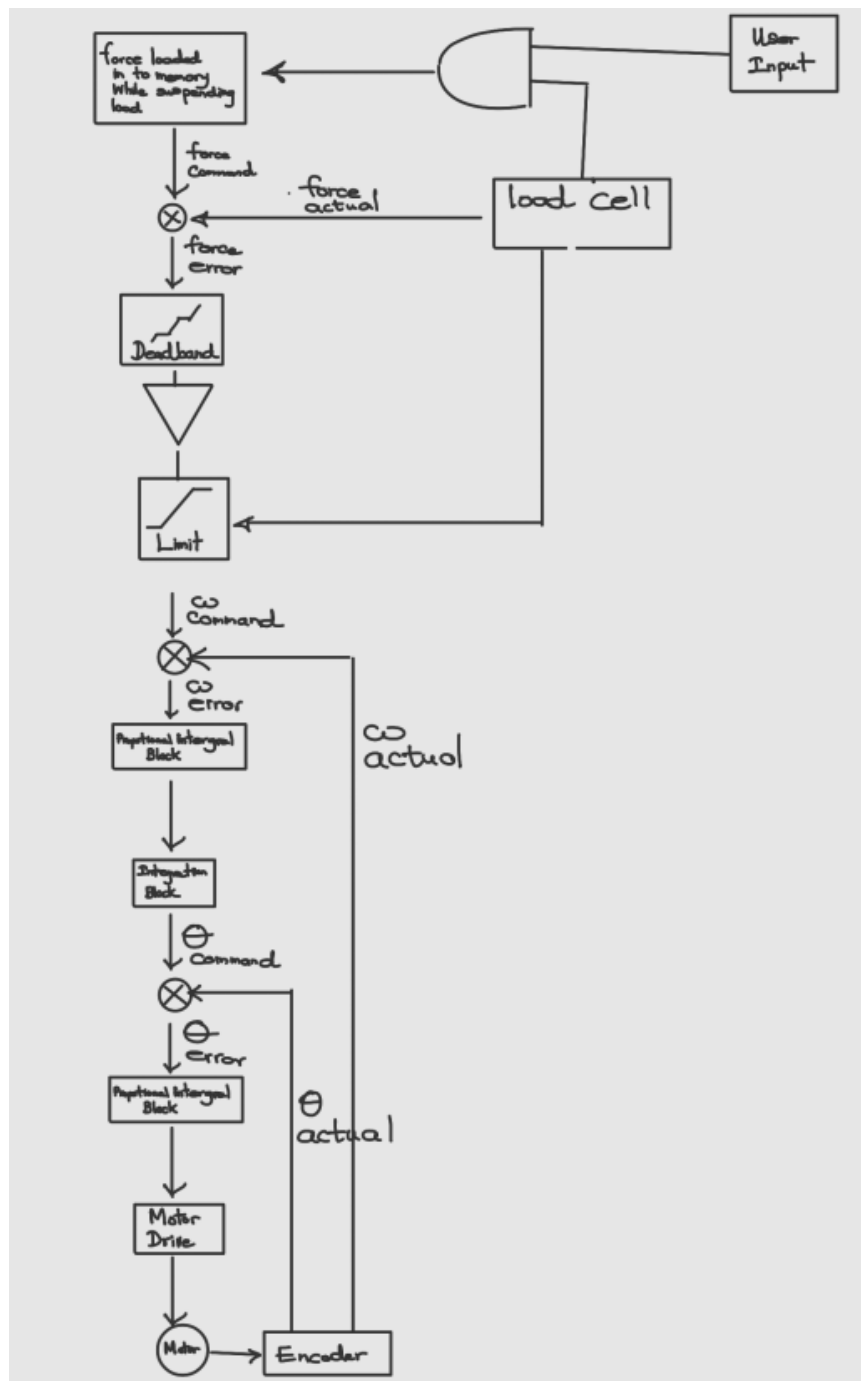


Figure 6: Design for controlling servo motor-Block diagram 3

5 Conceptual Designs for signal input

5.1 Design 1

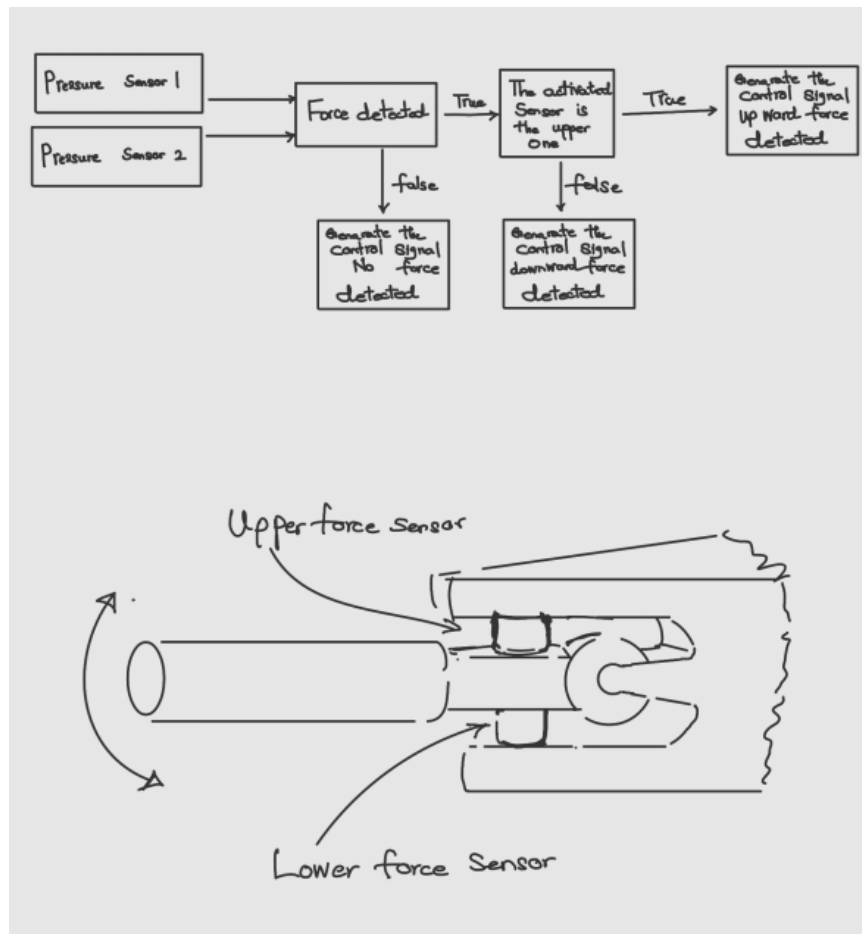


Figure 7: Design 1

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

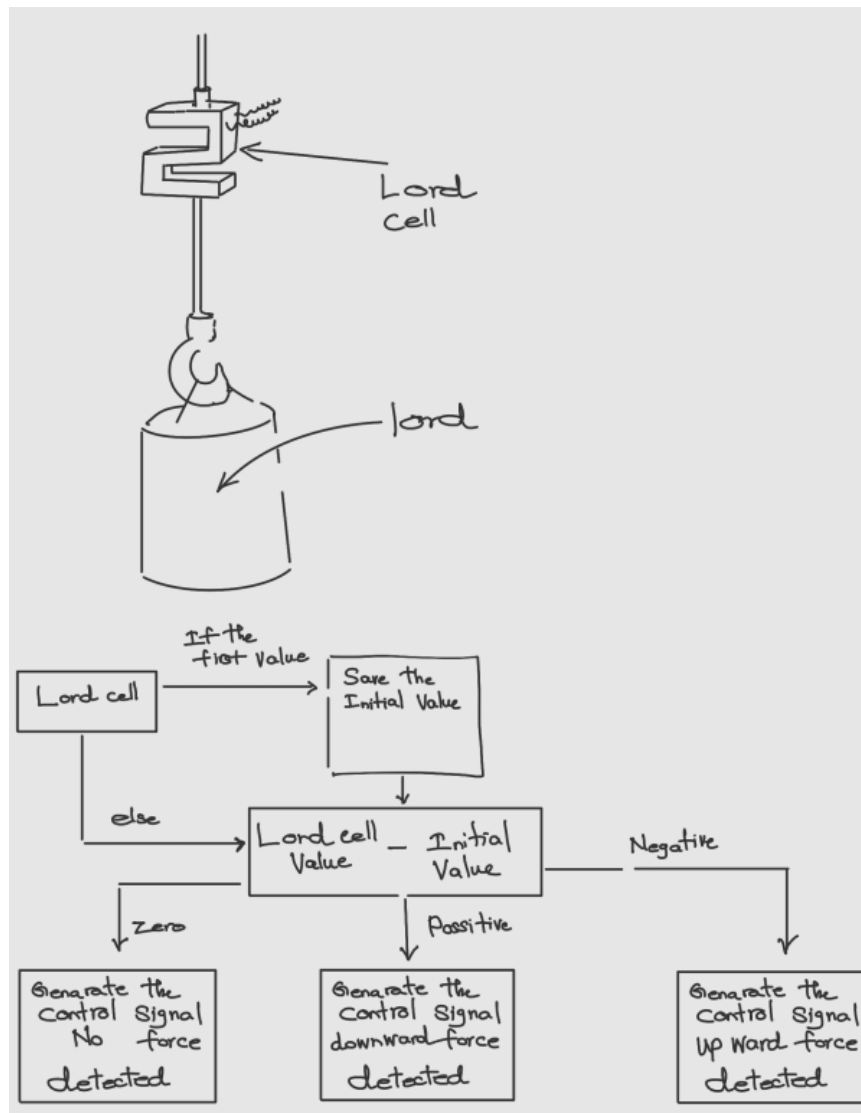


Figure 8: Design 2

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

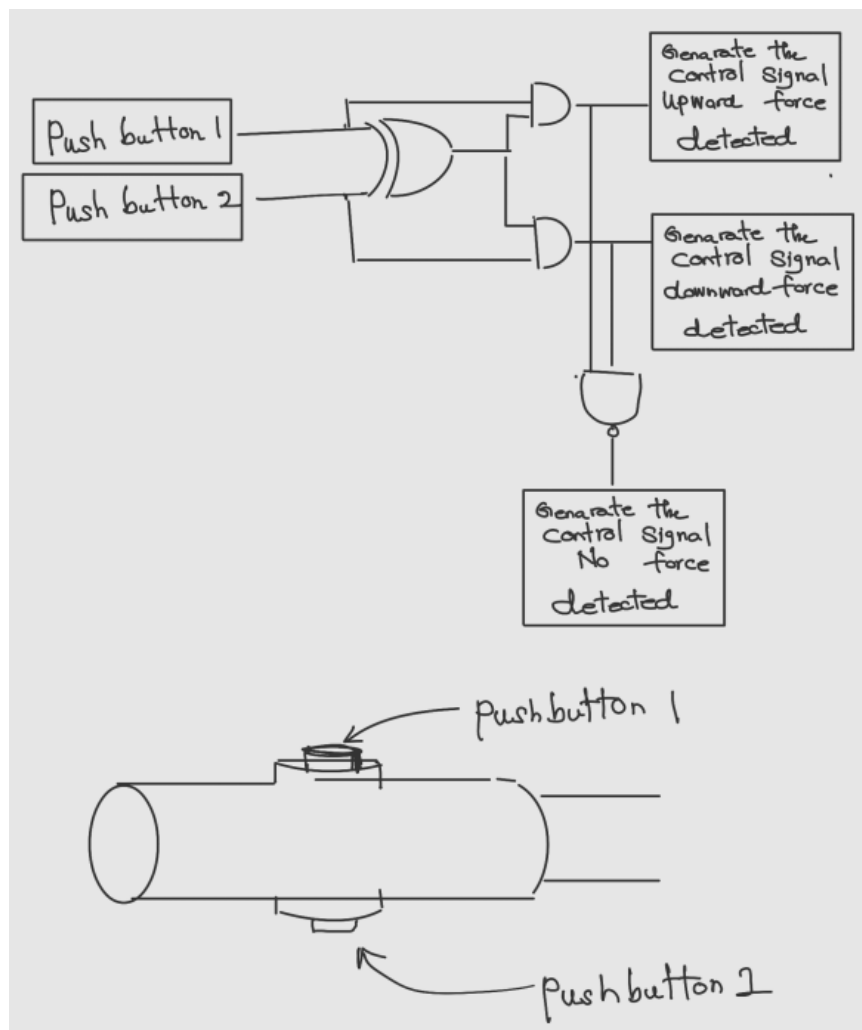


Figure 9: Design 2

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

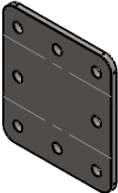
The enclosure design of the prototype for the Zero Gravity Arm/Lift Assist project is pivotal in ensuring the functionality, safety, and durability of the device within industrial settings. Crafted from high-strength materials such as reinforced plastics or metals, the enclosure provides robust protection 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.

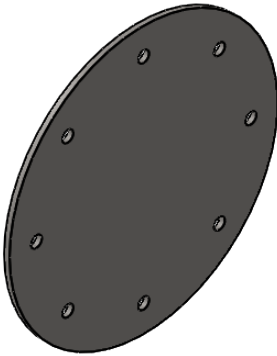
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Column



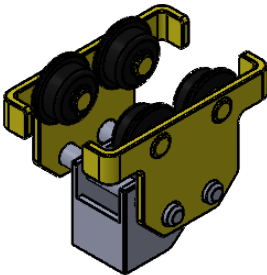
Arm Base



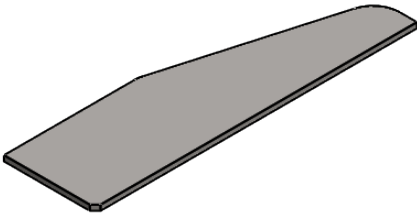
Base column




Axle



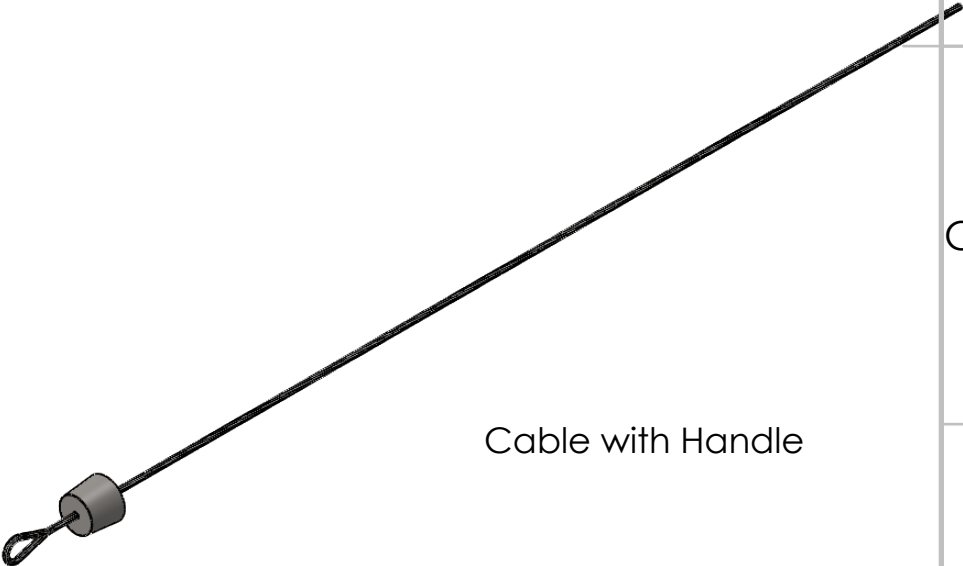
Beam Trolley



Column Base supporter



Axle and column joint



Cable with Handle

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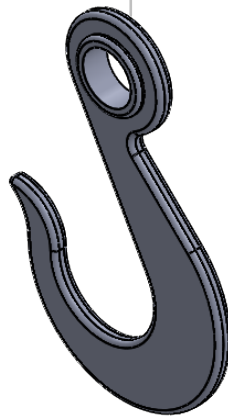
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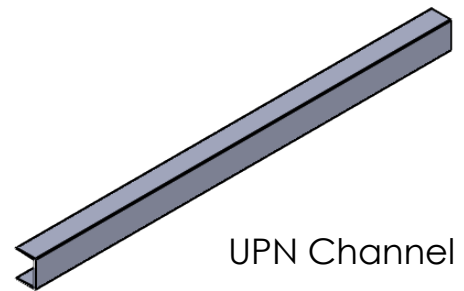
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CHK'D						
APPV'D						
MFG						
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Flange

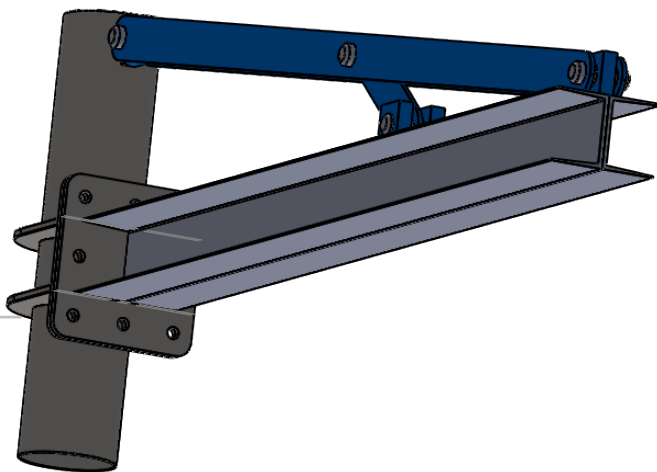


Hook

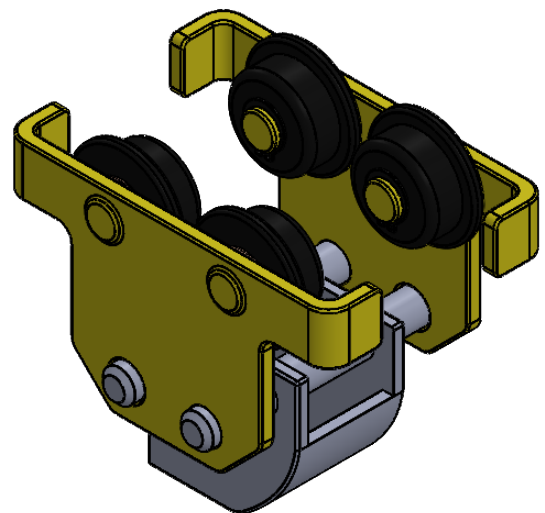


UPN Channel

Sub Assemblies



Axle assembly



Beam Trolley

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Part Files and Sub assembly

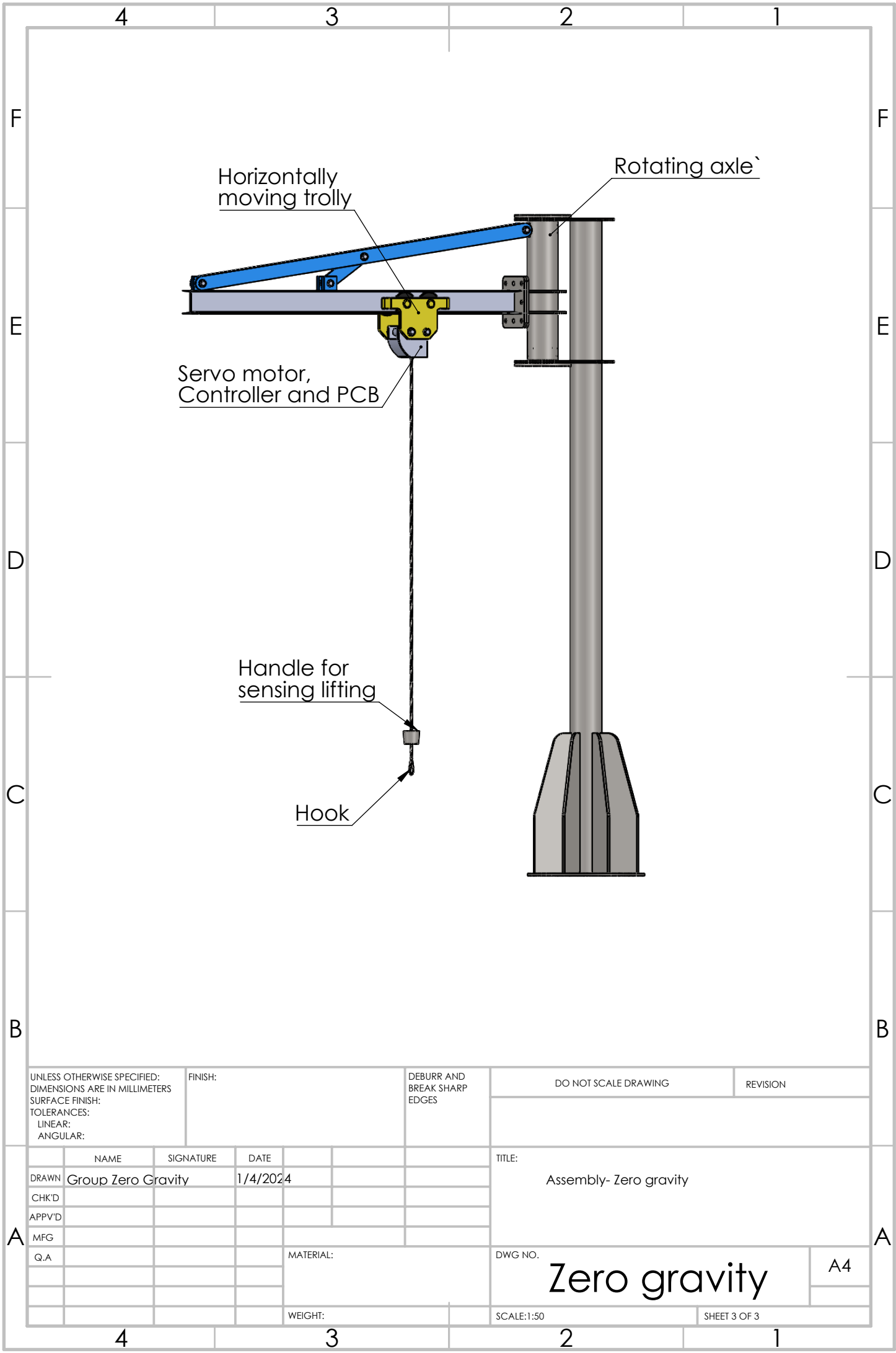
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Zero gravity

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SHEET 2 OF 3



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Assembly- Zero gravity

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Zero gravity

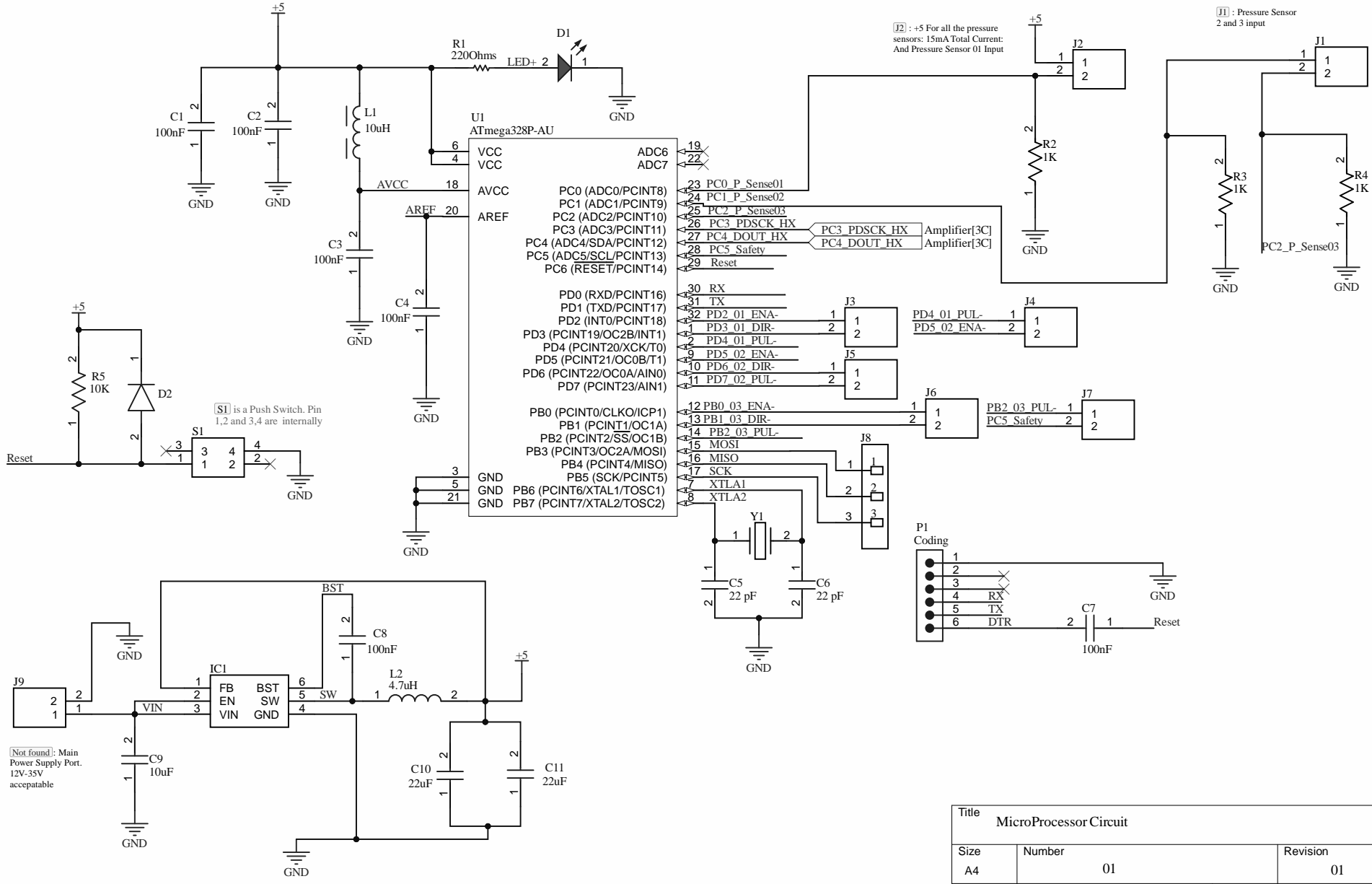
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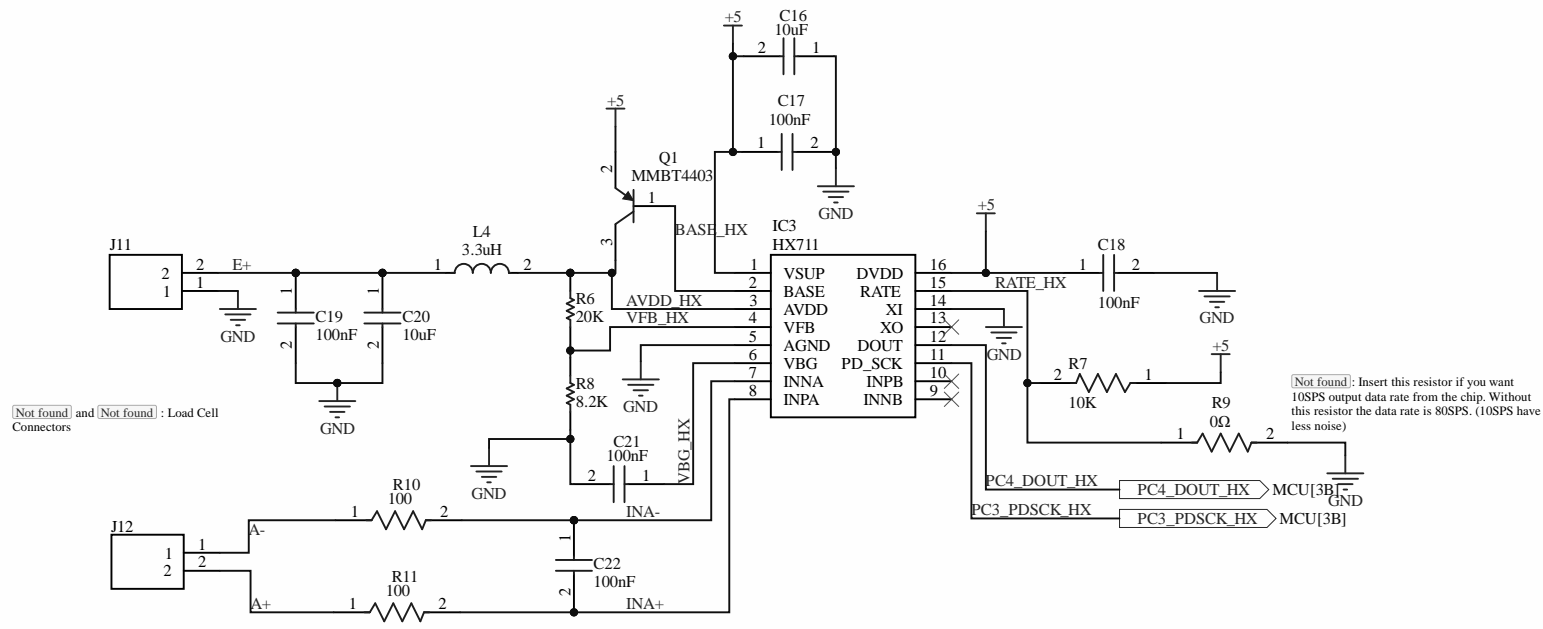
SHEET 3 OF 3

7 Schematic and PCB design of the prototype

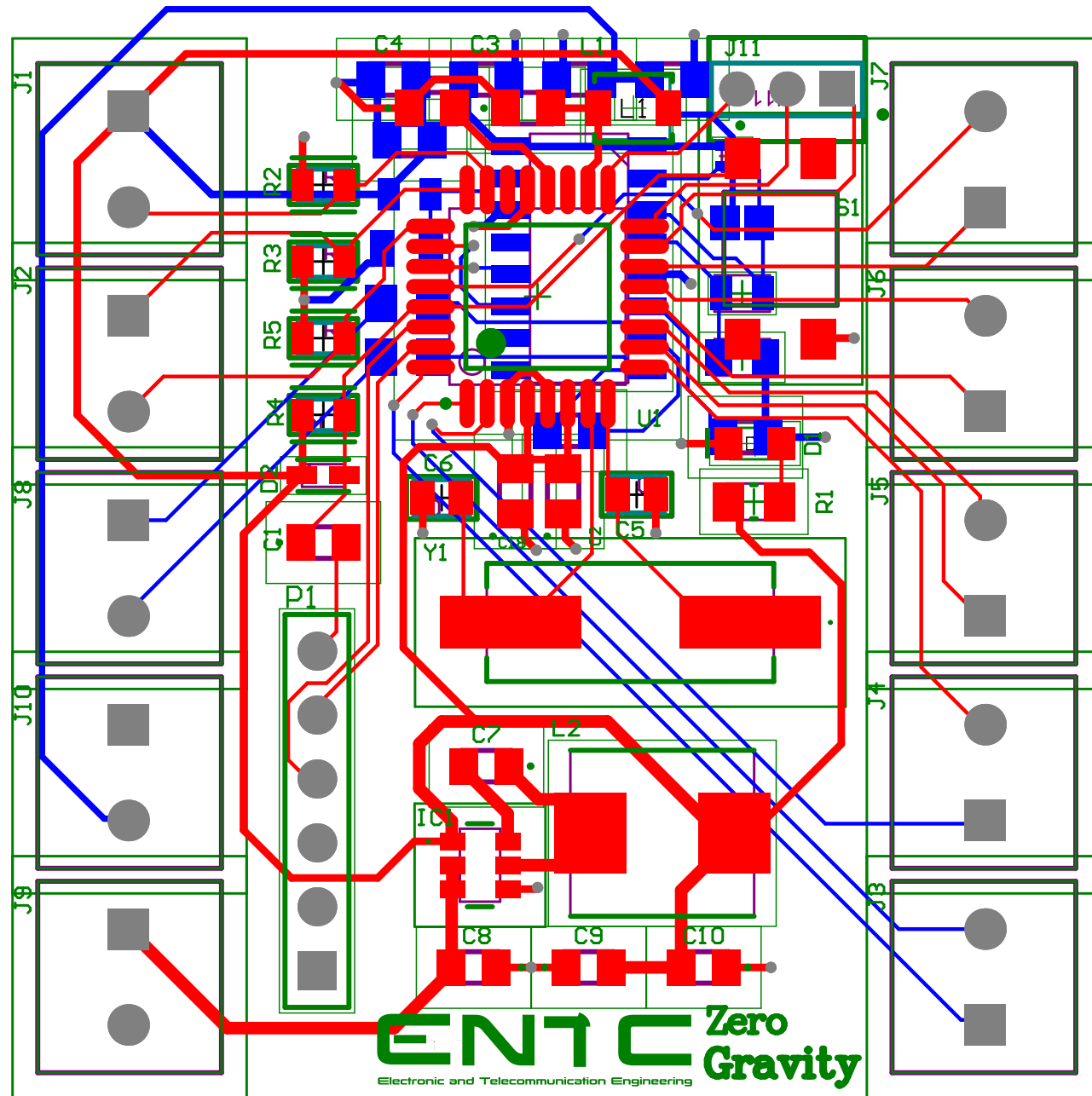
The Box Lifting Device utilizes an Atmega328P chip as its microcontroller. To power up the stepper motor, a 12V AC to DC adapter is used, which is then stepped down to 5V using a buck converter to supply the necessary voltage to the Atmega chip. Additionally, two pressure sensors are integrated with 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.



Title		
MicroProcessor Circuit		
Size	Number	Revision
A4	01	01
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File: C:\Users\...MCU.SchDoc		Drawn By: Ruchira Abeywardhane



Title			Load Cell Amplifier Circuit
Size	Number	Revision	
A4	02	01	
Date:	6/23/2024	Sheet 2 of 2	
File:	C:\Users\...\Amplifier.SchDoc	Drawn By: Ruchira Abeywardhane	



ENTC Zero Gravity
Electronic and Telecommunication Engineering