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Design Report
Zero Gravity Lifting Mechanism

by:

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Contents

1. Abstract

This project focuses on the development of a zero-gravity lifting mechanism that reduces user effort by dynamically counterbalancing the load during lifting tasks. These systems are widely applicable in sectors such as manufacturing, warehousing, and construction, where repetitive material handling leads to fatigue and injury risks.

Project criteria include:

- Construction of a manipulator arm similar to the INDEVA Liftronic Easy
- Deployment of a suitable load sensor for force detection
- Development of a control algorithm for lifting with minimal user effort

The design process follows the Inclusive Design Toolkit by the University of Cambridge, progressing through the phases of *Manage, Explore, Create, and Evaluate*. Evaluation of concepts, and components was carried out using scoring matrices. The resulting system demonstrates ergonomic, responsive, and intuitive lifting performance, aligning with the principles of inclusive design.

2. Manage: Understanding the Project and Planning

2.1 Project Overview

The primary objectives of the project focus on the development of a zero gravity lifting mechanism designed to assist in the handling and movement of medium loads with minimal physical effort. The system aims to integrate a guided support structure and smooth motion control to allow for precise and ergonomic load lifting. Key goals include enhancing workplace safety, reducing operator fatigue, and enabling customizable control settings for various industrial environments through an intuitive user interface and secure gripping technology.

2.2 Key Features and Innovations

The development of the Zero Gravity Lifting Mechanism introduces several key features and innovations. These include an adjustable lifting capacity to accommodate loads of varying weights, and smooth and controlled motion to ensure precise handling and movement. An intuitive user interface is implemented to enable ease of operation, while customizable controls allow the system to be adapted for different work environments and user needs. The mechanism features secure grip systems designed to prevent slippage during lifting operations, along with emergency stop functions to enhance user safety. Additionally, the system promotes comfortable operation, reducing physical strain and improving overall ergonomics for the operator.

2.3 Research and Literature Review

The investigation involved a review of commercially available lifting assist systems, with a focus on solutions demonstrated by Gorbel and other industry-leading technologies. Resources included demonstration videos and detailed product brochures.
The *Gorbel G-Force® and Easy Arm®* systems, explored through brochures and YouTube demonstrations, provided key insights into intelligent lifting devices that blend human control with mechanical assistance. These systems emphasize features such as zero-gravity motion, float mode for fine adjustment, and precision lifting with minimal effort, all of which are highly relevant to the proposed mechanism.

Notable videos such as the Easy Arm Demonstration and G-Force® Q and iQ Comparison showcased the integration of ergonomics, safety features, and responsive load handling. Another video on Advanced Features highlighted smooth motion control and programmable handling settings.
The reviewed brochures (Gorbel G-Force® Q/iQ Brochure and Easy Arm® BX Model Overview) provided detailed specifications, focusing on load capacity ranges, safety systems, and user-friendly interfaces. These insights directly influenced the design goals of the Zero Gravity Lifting Mechanism, particularly in achieving adjustable lifting capacity, intuitive operation, and safe load handling.
This review confirms that technologies used in modern lifting assists such as smart motion control, secure gripping mechanisms, and operator-centric design can be effectively adapted and optimized for the project's objectives.

2.4 Stakeholder Map

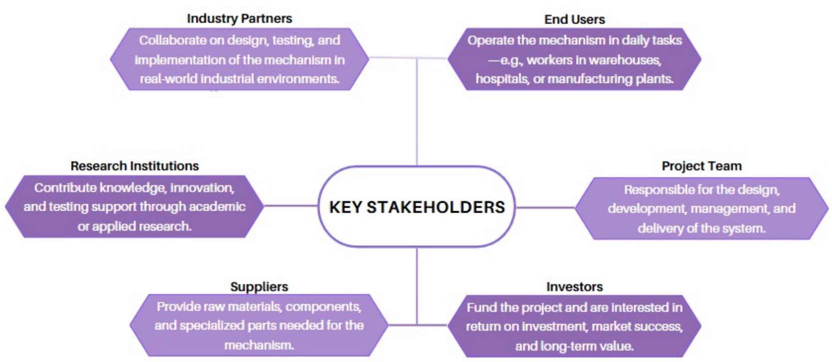


Figure 1: Key Stakeholders

2.5 Objectives

The primary objectives of the project focus on the development of an intelligent zero gravity lifting mechanism designed to assist in the handling and movement of medium loads with minimal physical effort. The system aims to integrate a guided support structure and smooth motion control to allow for precise and ergonomic load lifting. Key goals include enhancing workplace safety, reducing operator fatigue, and enabling customizable control settings for various industrial environments through an intuitive user interface and secure gripping technology.

2.6 Action Plan

The action plan includes several key phases: beginning with the conceptual and mechanical design of the lifting system, followed by the selection of appropriate materials, actuators, and sensors to ensure precision and safety. The next phase involves building the mechanical structure and integrating the control system for smooth operation. A slider or guided support system will be added to enhance stability and movement accuracy. The prototype will then undergo iterative testing and refinement, leading to final validation through both simulation and real-world performance assessments.

3. Explore: Understanding User Needs

Understanding user requirements is crucial to the development of an efficient and safe zero-gravity lifting mechanism. Through user observation and evaluation of existing commercial products, key concerns and expectations were identified. These insights help align the design with real-world applications in workshops, factories, warehouses, and assembly lines.

3.1 Workshop User Observations

Through observation and feedback from workshop users, the following points were noted:

- **Ergonomics & Safety:** Users frequently experience strain from lifting, especially during repetitive tasks. There is a clear demand for safer load handling with features like emergency stop mechanisms, locking systems during power failure, and automatic halt on unsafe acceleration or obstruction.
- **Operation Simplicity:** Users prefer intuitive controls requiring minimal input. Devices with over-complicated interfaces are not suitable for fast-paced, practical environments.
- **Precision & Smooth Handling:** Smooth and controlled movement with minimal user effort is expected. This is particularly important for operations requiring accurate positioning.
- **Modularity & Adaptability:** Users want devices that can use different attachments to handle various object types. Multi-directional motion across 1D, 2D, and 3D planes is also needed.
- **Reliability:** The device must deliver consistent performance and have robust construction to withstand long hours of use in harsh environments.

3.2 Industry Perspective

From a business and investment viewpoint, stakeholders prioritize:

- **Cost-Effectiveness:** Both initial investment and operational costs must remain low to justify return on investment (ROI).
- **Durability and Longevity:** A long-lasting, low-maintenance system reduces downtime and replacement frequency.
- **Productivity and Efficiency:** Faster, smoother operations translate into increased output.
- **Integration Capability:** The mechanism should be compatible with existing workstations or processes to prevent major workflow disruptions.

3.3 Engineering and Design Requirements

Engineers and designers identified the following needs:

- **Advanced Control Systems:** Capable of sensing load position and movement for real-time adjustment.
- **Swing Reduction and Load Stability:** Systems should include damping mechanisms to avoid swinging during movement or load release.
- **Environmental Suitability:** The device should perform reliably in dusty, oily, or compact environments.
- **Cable & Power Management:** Systems should avoid cable tangling and maintain clean, organized routing.

3.4 User Need List

The following table outlines the comprehensive user and stakeholder needs, based on observations and research:

No.	Need	Rationale
1	Ergonomic Operation	Reduce user strain and fatigue during extended use. Prevents injuries and improves comfort.
2	Safety Features	Locking mechanism during power loss, emergency stop button, obstruction detection, and acceleration limiters to ensure safe operation.
3	Intuitive Interface	Simple controls with minimal training required; suitable for workshop environments.
4	Precise Load Positioning	Smooth, multi-axis control with fine adjustments for tasks requiring accurate alignment.
5	Multi-Directional Movement	Capability for vertical, and horizontal to enhance versatility in object placement.

6	Reliable Performance	Consistency in motion control and power delivery; low error rate in repeated tasks.
7	Modular and Compact Design	Adaptability to different spaces and portability for shifting within work areas.
8	Durability and Robustness	Withstand rough conditions like workshop heat, dust, oil, and frequent operation cycles.
9	Low Maintenance	Reduce need for frequent servicing; easy to inspect and replace critical components.
10	Energy Efficiency	Reduce operational power draw with efficient motors or hybrid systems.
11	Affordable Design	Use locally available materials and cost-effective components to make the solution feasible for SMEs and local industries.
12	Compliance and Certification	Adhere to safety and manufacturing standards (e.g., ISO, local labor safety laws).
13	Aesthetic and Brand Appeal	Ensure the device looks professional and reflects quality, helping marketability.

User observations were primarily conducted through the analysis of publicly available YouTube videos showcasing real-world user interactions with manual and automated lifting mechanisms. The list of referenced videos is provided in the appendix.

4. Create: Generating and Refining Design Concepts

4.1 Review of Existing Solutions

Modern lifting assist systems successfully incorporate zero-gravity principles through counterbalancing mechanisms and ergonomic design. These commercial solutions inform the foundational aspects of our design approach.

Gorbel G-Force® and Easy Arm®

The Gorbel Easy Arm® and G-Force® systems are advanced intelligent lifting devices that combine the precision of robotics with the responsiveness of a human touch. These systems feature servo-driven actuation with float modes, allowing operators to manipulate loads effortlessly with smooth, fluid motion. The Easy Arm® integrates an articulating jib with an enclosed track, enabling high-speed, high-precision lifting with reach-in capability and consistent balance across a defined workspace.

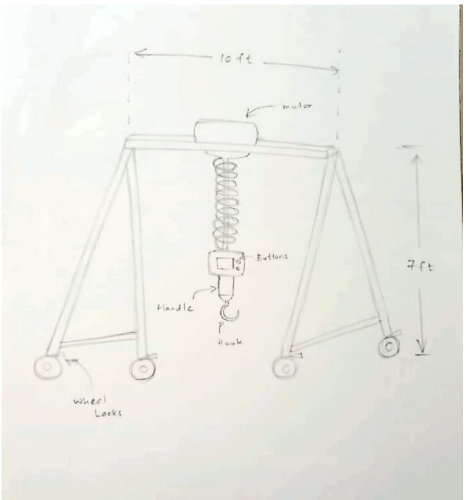
Dalmec Industrial Manipulators

Dalmec offers a broad range of pneumatic manipulators tailored for specific payload geometries. These manipulators feature articulated arms with customized end-effectors and load balancers that enable ergonomic, zero-gravity motion control. They are widely used in automotive and packaging industries for consistent and safe material handling.

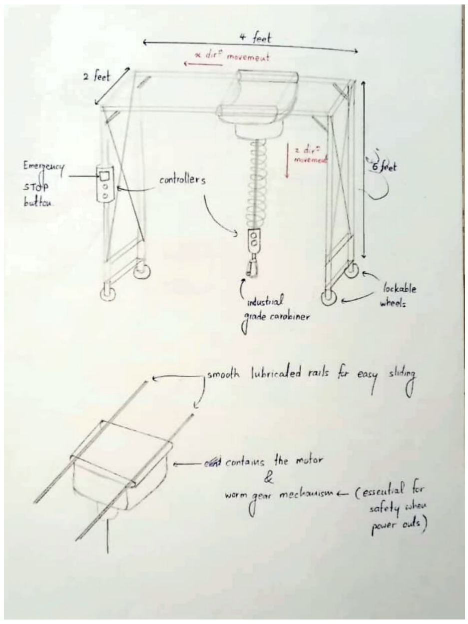
Summary

These systems demonstrate efficient load management, ergonomic articulation, and intelligent balance—principles that directly influence our conceptual zero-gravity lifting design.

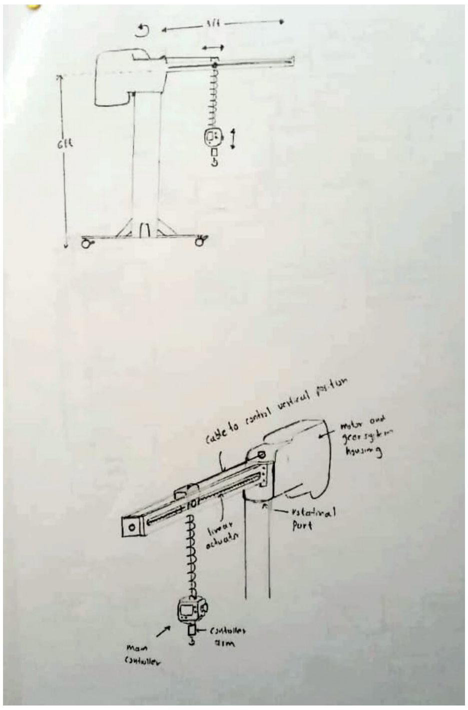
4.2 Conceptual Design



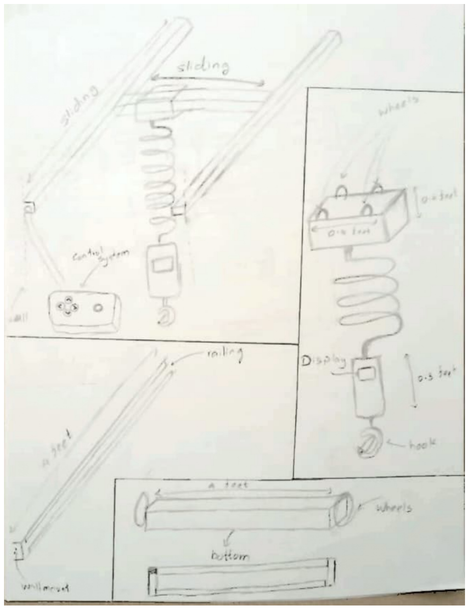
(a) Conceptual Design 1



(b) Conceptual Design 2

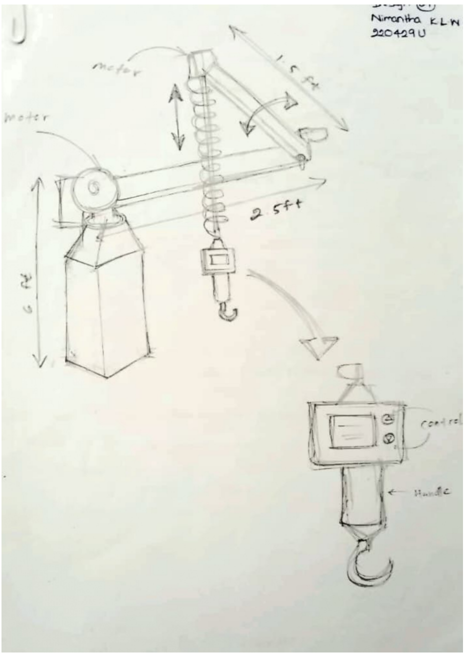


(c) Conceptual Design 3

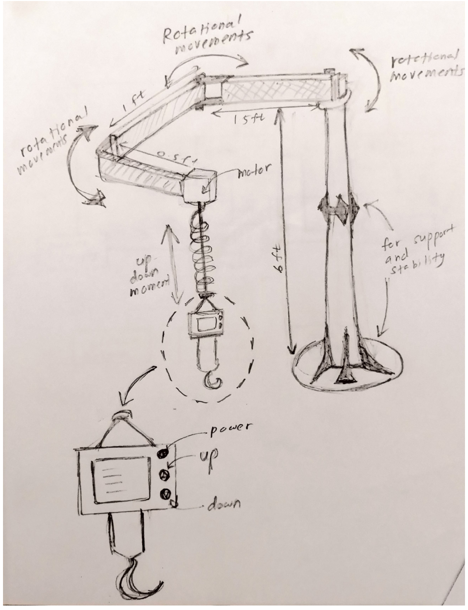


(d) Conceptual Design 4

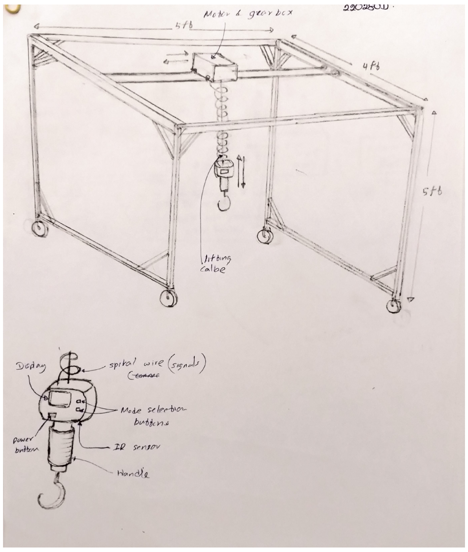
Figure 2: Conceptual Designs 1–4



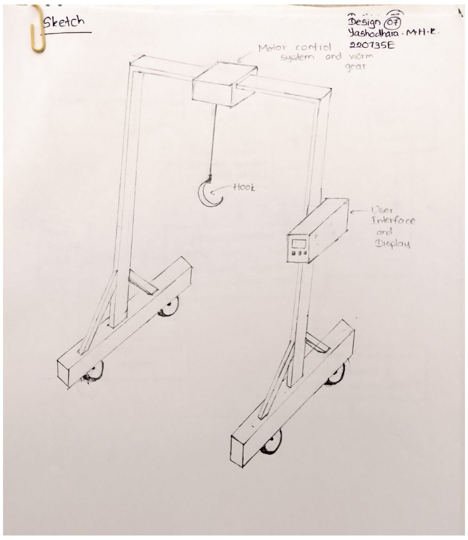
(a) Conceptual Design 5



(b) Conceptual Design 6



(c) Conceptual Design 7



(d) Conceptual Design 8

Figure 3: Conceptual Designs 5–8

4.3 Evaluation Tables

	Criteria	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8
Design	User-friendly Controls (15)	12	10	12	13	9	14	11	9
	Mobility (10)	10	9	7	5	10	7	10	5
	Precision (15)	12	10	12	13	12	14	12	10
	Safety Mechanism (15)	15	15	15	15	15	15	15	15
	Durability and Maintenance (10)	8	8	7	8	8	7	7	7
	Cost Effectiveness (15)	11	12	8	7	8	10	10	7
	Ergonomics and Design (20)	16	14	13	15	14	18	11	10
Total	**(out of 100)**	84	78	74	76	76	85	77	63
Block Diagram	Input/Output Handling (10)	7	6	7	7	9	9	7	8
	Functionality (20)	15	16	16	17	18	19	17	16
	Manufacturing Feasibility (15)	12	12	13	11	12	13	13	11
	Cost Efficiency (15)	11	11	11	11	11	10	11	12
	Performance (15)	9	11	9	10	10	12	10	10
	Scalability (10)	8	8	8	8	8	8	8	8
	Power Consumption Efficiency (15)	12	12	12	11	11	10	12	12
Total	**(out of 100)**	74	76	76	75	79	81	78	77
Flowchart	End goals/Outcomes (20)	17	17	15	15	17	14	12	12
	Input/Output Handling (10)	9	8	8	7	8	9	7	7
	Decision points and Conditionals (10)	7	7	6	6	7	5	3	5
	Error and Exception Handling (15)	10	8	8	7	6	6	7	8
	Process Efficiency (20)	12	12	14	18	14	16	12	14
	Practicality of the logic (15)	9	8	8	10	9	9	7	10
	Complexity (10)	7	7	8	7	7	5	7	8
Total	**(out of 100)**	71	67	67	70	68	64	55	64
Total	**(out of 300)**	229	221	217	221	223	230	210	204

Table 2: Evaluation Comparison

4.4 Cross-Pollinated Design

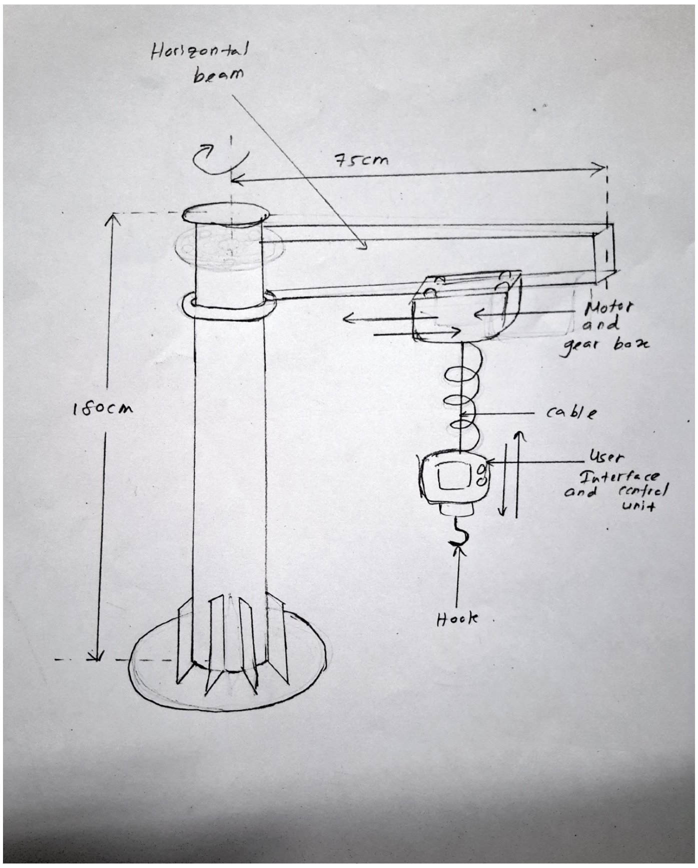


Figure 4: Radial Arm Design

4.5 Selected Design (with justification)

After evaluating the eight initial designs, we identified two main design approaches. Taking into account the strengths and weaknesses of both, we decided to move forward with a **radial arm design**, which offers significant advantages over our initial concept. The key improvements and refinements in this iteration include:

- **More Usable Workspace:** The new design provides a much less restrictive environment for users to move objects freely, eliminating the need for unnecessary supporting bars or structures that could get in the way.
- **Better Accessibility:** Unlike fixed or linear mechanisms, the radial arm design moves in both the r (radial) and *theta* (rotational) directions, allowing access to any point within a circular workspace. This makes it significantly more versatile than stationary or purely linear mechanisms.

- **Reduced Oscillations and Increased Stability:** By using a single primary arm with an integrated sliding mechanism, the system minimizes unnecessary movement and oscillations, improving overall stability and precision.
- **Simplified Assembly and Maintenance:** With fewer moving parts, the design is not only easier to put together but also much simpler to maintain. The reduced modular complexity ensures faster disassembly when needed.
- **More Cost-Effective and Reliable:** By optimizing the number of mechanical components, the design keeps production costs down while improving reliability over time.
- **Optimized Power Efficiency:** The radial movement requires less energy compared to alternative designs, making the system more power-efficient without compromising functionality.
- **Scalability and Future-Proofing:** The modular structure allows for easy modifications and upgrades, making it adaptable for future enhancements and different operational needs.

By incorporating these improvements, the cross-pollinated design strikes the right balance between **efficiency, usability, precision, and long-term sustainability**. This makes it the most practical and effective choice for our zero-gravity lifting system.

5. Evaluate: Final Design Decisions and Technical Implementation

5.1 Evaluation of Key Components

5.1.1 MCU

When selecting a microcontroller (MCU) for our device, we narrowed down the available options by considering several key factors. We prioritized MCUs that support registry-level coding for fine-grained hardware control. The availability of a built-in IDE and strong manufacturer support were important to ensure smooth development and troubleshooting. Additionally, we evaluated the number of pins to match our input/output needs, considered the ease of soldering for efficient and reliable assembly, and ensured overall affordability to stay within budget.

After narrowing down the options to seven microcontrollers, we conducted a detailed evaluation to identify the most suitable choice for our device. The evaluation process and the criteria considered are outlined below.

Marking Criteria		
Criteria	Weight	Explanation
Core Architecture & Performance	10	Speed, modern features, pipeline
Memory and Storage	10	RAM + Flash size and flexibility
Power Efficiency	10	Especially important for E-Ink
Communication Interfaces	10	SPI, I2C, UART, USB, CAN, etc.
Analog and PWM Capabilities	10	ADC resolution, channels, PWM
Safety and Security	5	Brown-out detect, WDT, ECC, etc.
Library Availability	10	Community & official support
IDE and Coding Environment	10	Ease of use, toolchain quality
Register-Level Coding	5	Docs, accessibility, transparency
Manufacturer Support	10	Quality of datasheets, examples, etc.
Affordability	10	Availability and price in 2024/2025

MCU	ATSAMD21G18	LPC845	ATmega1284P	MSP432P401R	ATmega2560	EFM32ZG	PIC16F877A
Datasheet	SMART SAM ...	LPC84x_2.pdf	ATmega164...	slas826e.pdf	ATmega 640 ...	EFM32ZG ...	39582C.pdf
Arch (10)	8	7	6	9	6	6	3
Mem (10)	9	8	7	10	6	4	2
Power (10)	7	8	5	9	5	10	6
Comm. (10)	8	7	7	8	7	7	6
Analog (10)	8	8	7	9	7	6	6
Security (5)	4	3	3	5	4	4	2
Libs (10)	8	6	8	5	9	5	4
IDE (10)	8	7	9	6	9	6	7
Reg. (5)	8	8	9	7	10	6	8
MFG Sup. (10)	9	8	8	0	10	7	7
Cost (10)	4	9	8	1	9	7	9
Total (100)	81	79	77	69	82	68	60

5.1.2 Motor

For our zero gravity lifting machine, we needed to lift a 12 kg load at 0.2 m/s using a winch system. This required a torque of 11.78 Nm at the winch. Including a 100% safety margin for friction and inertia, the total mechanical power needed was 449 Nm·RPM. Since our available motors provide only 1.2 Nm torque, we chose a gear ratio of approximately 10:1 to meet the torque requirement efficiently.

Based on the above criteria, we narrowed down the motor options to the TS Series, ESS Series, and P Series. A detailed evaluation of these motor types is provided below.

Marking Criteria

Parameter	Weight (%)	Reason for Weighting
Torque	10%	Critical for motor performance (all are equal)
Voltage Range	5%	Wider range offers flexibility
Current	5%	Affects power efficiency and heat generation
Holding Torque	10%	Essential for stepper motor stability (all are equal)
Step Angle	5%	Affects motor precision (missing value is penalized)
Encoder Resolution	10%	Higher resolution improves accuracy
Inbuilt Driver	-10%	inbuilt drivers tend to have realibility issues
Inbuilt Encoder	5%	Important for feedback control (all have it)
Weight	5%	Lighter is preferable but external driver consideration applies
Gear Ratio Compatibility	5%	Compatibility with 10:1 gear
Price	10%	Lower cost is better

Parameter	Weight (%)	TS Series	P Series	ESS Series
Torque	20%	20	18	18
Voltage Range	5%	4.5	4.5	5
Current	5%	5	5	4.5
Holding Torque	10%	10	10	10
Step Angle	5%	5	5	0
Encoder Resolution	15%	15	15	9
External Driver	10%	10	10	0
Inbuilt Encoder	5%	5	5	5
Weight	5%	3	3	5
Gear Ratio Compatibility	5%	5	5	5
Price	15%	13	9	9
Final Score (Weighted)	100%	95.5	89.5	70.5

5.1.3 Load Cell

To select a suitable load cell for our lifting machine, we considered several key criteria. The load cell needed a rated capacity of at least 15 kg to provide a sufficient safety margin for our 5 kg load. We also required an output sensitivity of 2.0 mV/V or higher to ensure accurate signal detection. Additionally, the load cell had to withstand at least 150% of the rated load to ensure safe operation under unexpected overloads. Lastly, compatibility with our electronics required an excitation voltage range of 5V–15V DC.

Based on these requirements, we decided to use a S-type load cells. A detailed evaluation done to identify the best load cell is provided below.

Parameters	Weight	# STC	# STG	# STB
Capacity	10	9	8	9
Output Sensitivity	20	15	18	15
None Linearity	20	16	18	16
SafeOverload	15	14	11	13
Zero Balance	10	8	8	8
Exitation voltage	10	10	10	10
Protection Grade (IP Rating)	15	11	14	10
Total	100	83	87	81

5.1.4 ADC

In selecting a suitable ADC for our system, we focused on key performance and practical criteria. The ADC needed to support low-noise differential instrumentation amplification to ensure accurate signal processing. It also required a gain setting appropriate for a full-scale input range of 20 mV, corresponding to a 0–10 kg load cell output. Additionally, the ADC had to be precise enough to detect weight changes as small as 4 grams, ensuring high-resolution measurements. We also considered cost-effectiveness and suitability for industrial applications.

Based on these requirements, we initially shortlisted four ADCs that met our criteria. A detailed evaluation was then conducted to determine the best fit for our application.

Category	Weight	ADS1232	HX711	ADS1263	NAU7802
Data Sheet		ads1232 (1).pdf	HX711.pdf	ads1263.pdf	NAU7802 Data Sheet V1.7.pdf
Resolution	15	15	15	15	15
PGA Gain Range	10	10	8	10	10
Noise Performance	20	20	12	20	15
Excitation Voltage	15	15	5	5	5
Sampling Rate	5	4	4	5	4
Channel Count	5	4	4	5	4
Communication	5	4	3	5	3
Power Consumption	5	4	5	3	4
Industrial Suitability	10	10	5	10	6
Affordability	10	8	10	3	7
Total	100	94	71	81	73

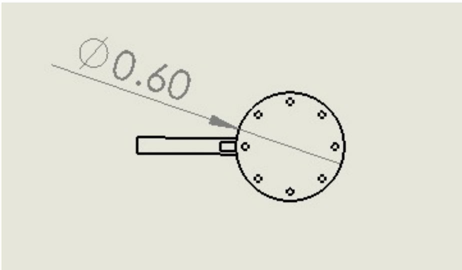
5.1.5 Linear Potentiometer

We chose to use a linear potentiometer in the handle to determine the moving speed. To ensure optimal performance, we analyzed and compared several available options in the market based on key criteria such as measurement range, linearity, durability, and compatibility with our system. These criteria are summarized in the table below. However, the final selection has not yet been made, and further evaluation is ongoing.

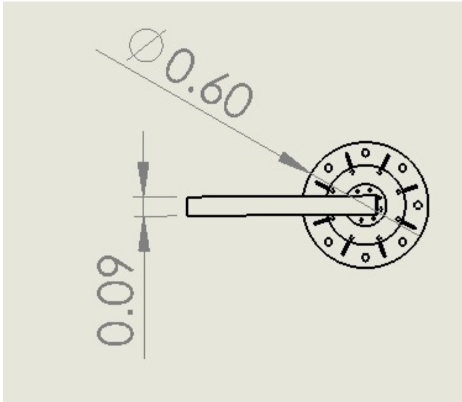
Marking Criteria		
Parameter	Weight (%)	Notes
Linearity	20%	Accuracy is key
Lifespan	15%	Critical for repeated/mechanical use
Spring Force	10%	Medium force preferred
IP Rating	10%	Dust/water protection
Stroke Range	10%	Longer = more flexibility
Mounting/Flexibility	5%	Integration ease
Price	15%	Lower is better (score inversely related to cost)
Compactness	15%	Smaller size for the same stroke = better

Model	Novotechnik T	Contelec KTR	Gefran PY1/PY2	TT LP-Series	UniMeasure LX-PA	Balluff BTL-S
Lin.	9	7	8	8	7	10
Life	10	7	9	7	6	10
Spring	8	9	8	9	8	N/A*
IP	8	9	8	8	6	10
Stroke	10	7	7	8	7	10
Mount	9	8	8	8	7	10
Price	6	8	7	8	9	3
Compact	6	8	7	9	6	4
Weighted Score	8.05	7.8	7.8	8.1	6.95	7.6

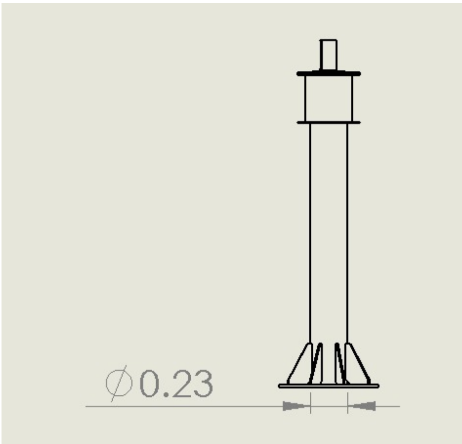
5.2 SolidWorks Design



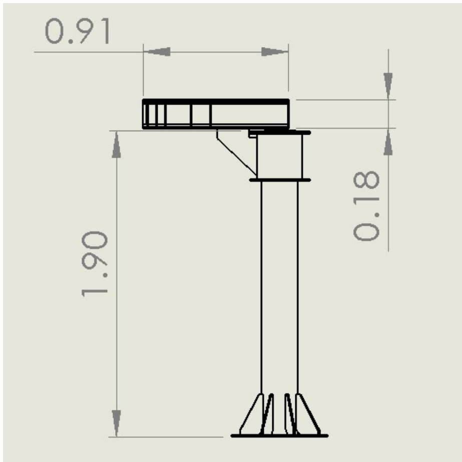
(a) Bottom View



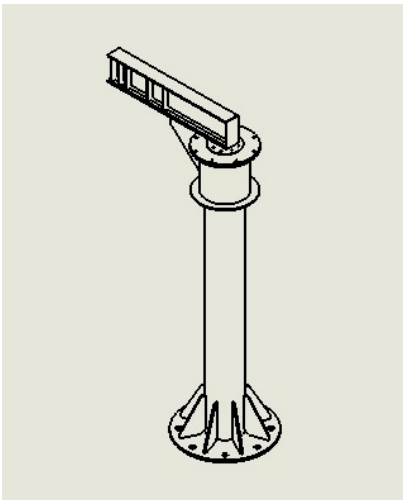
(b) Top View



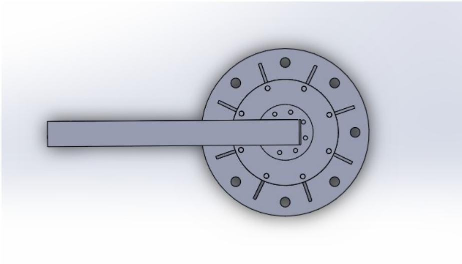
(c) Side View

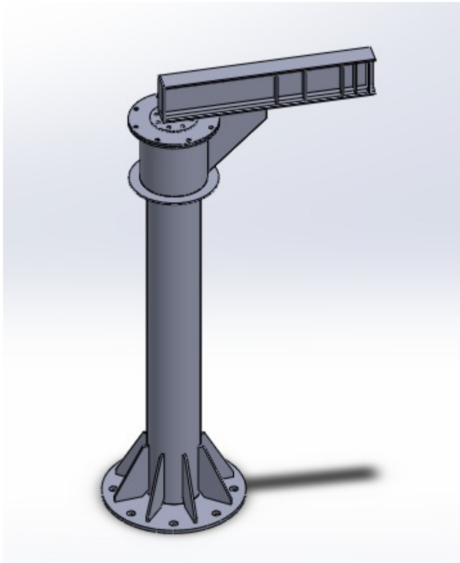


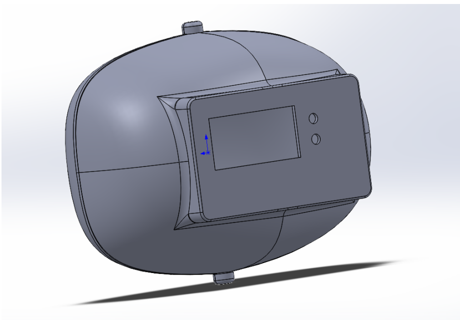
(d) Side View



(d) Isometric View







3D View

5.3 Block Diagram and Flow Chart

After analyzing the block diagrams and the flow charts drawn by each member of the team we came up with a final design and it is given below.

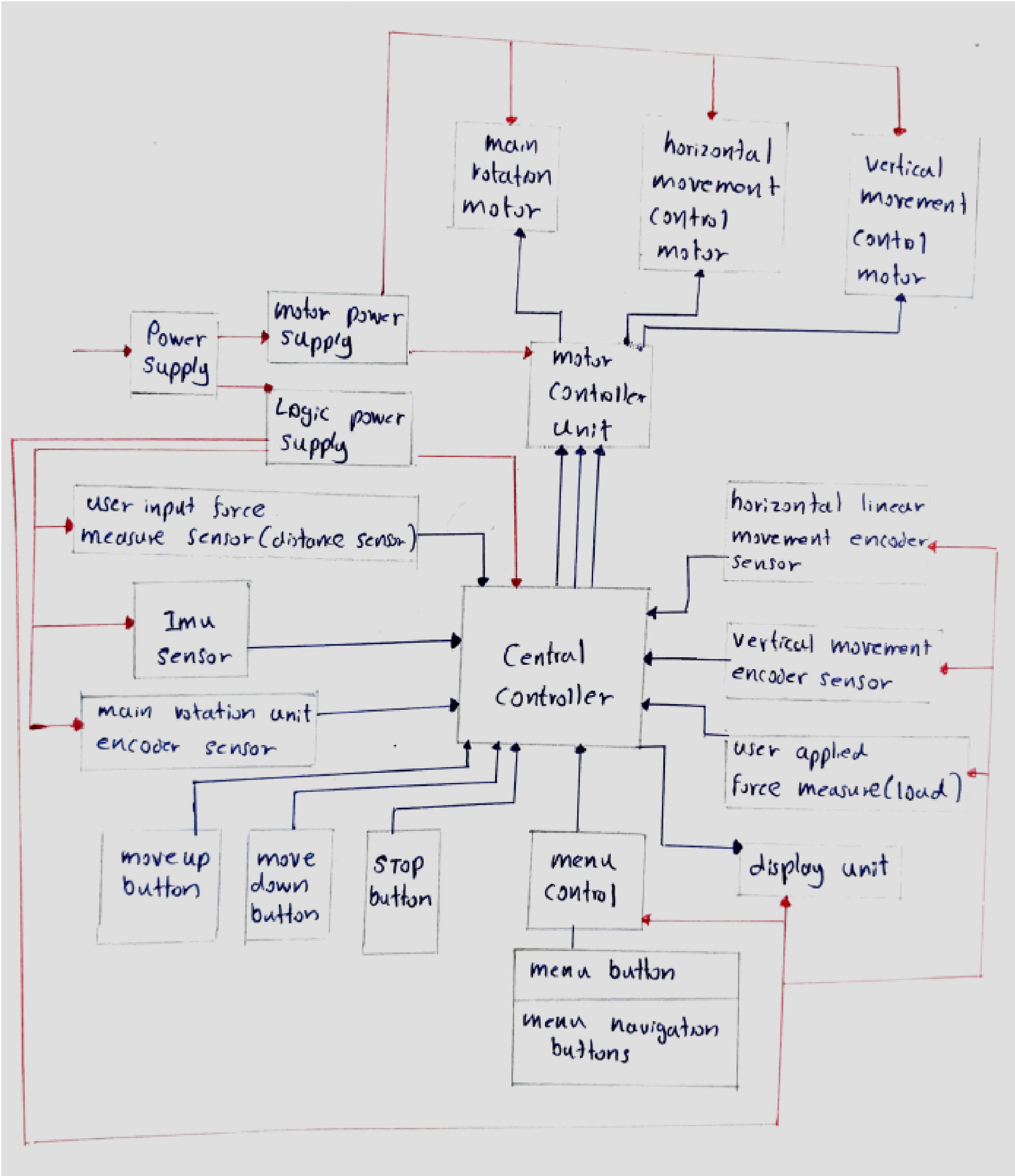


Figure 7: Block Diagram

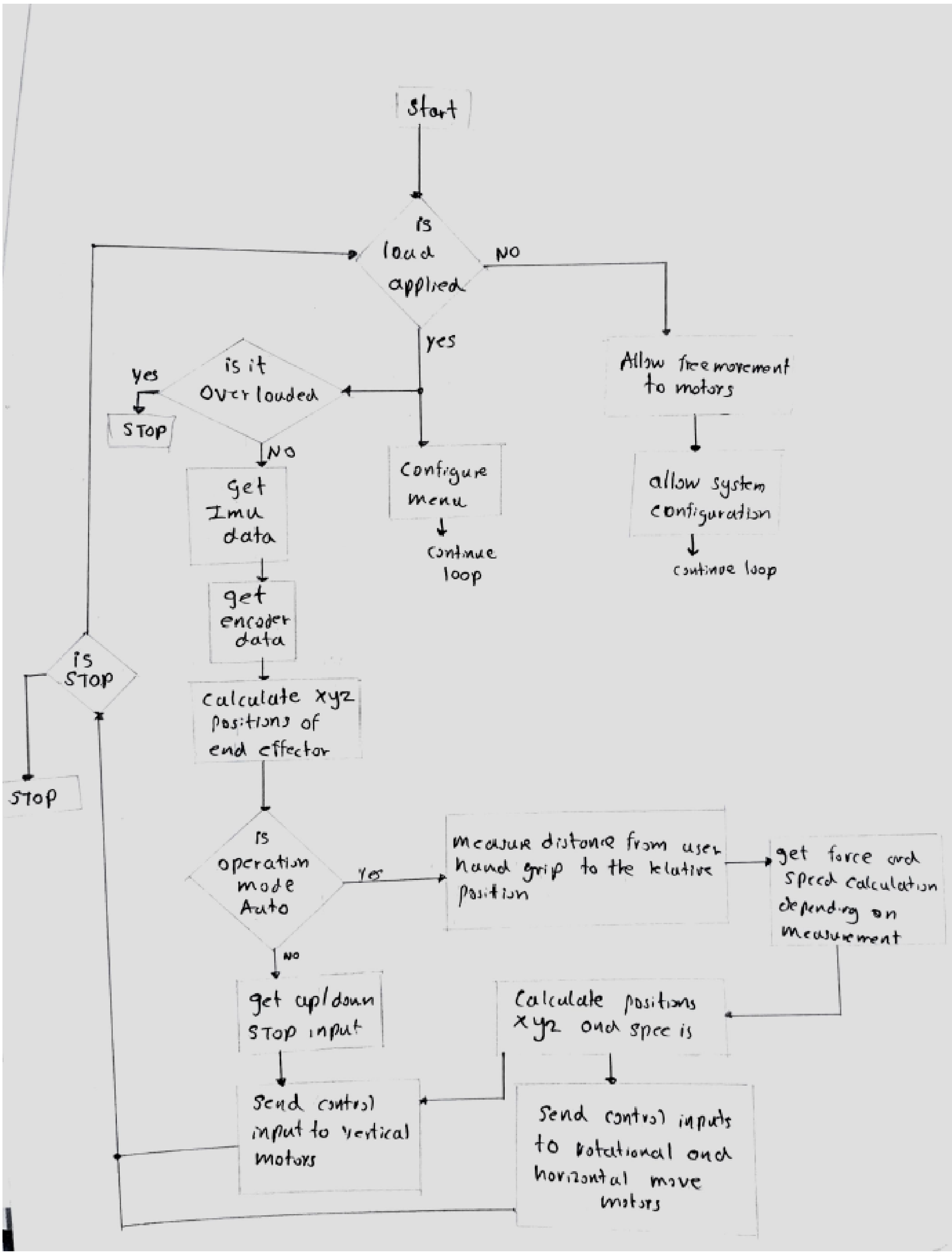
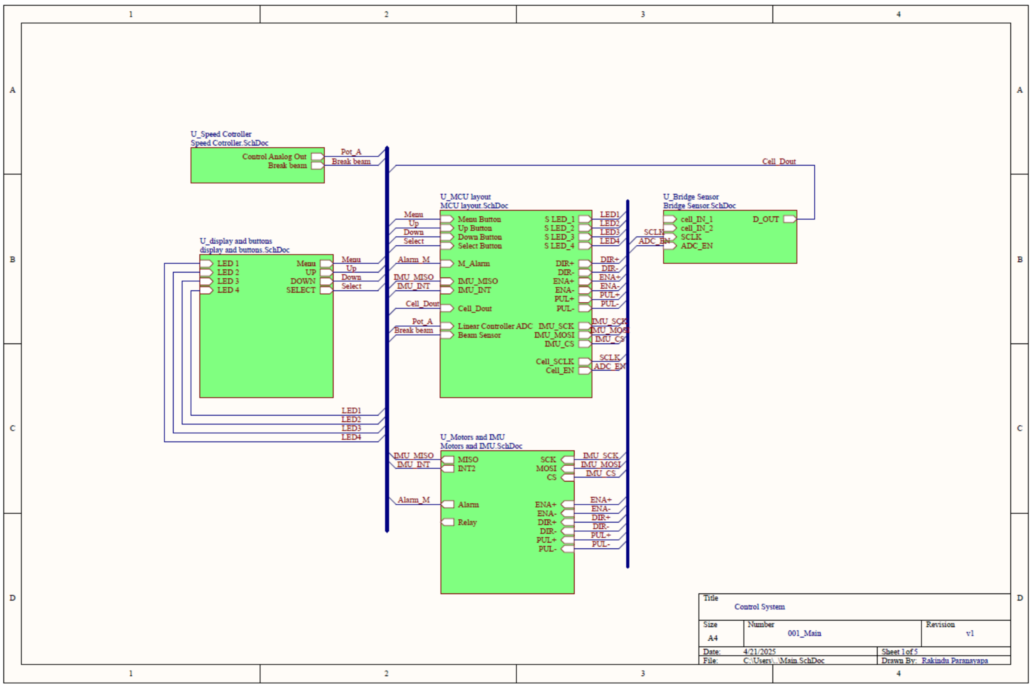
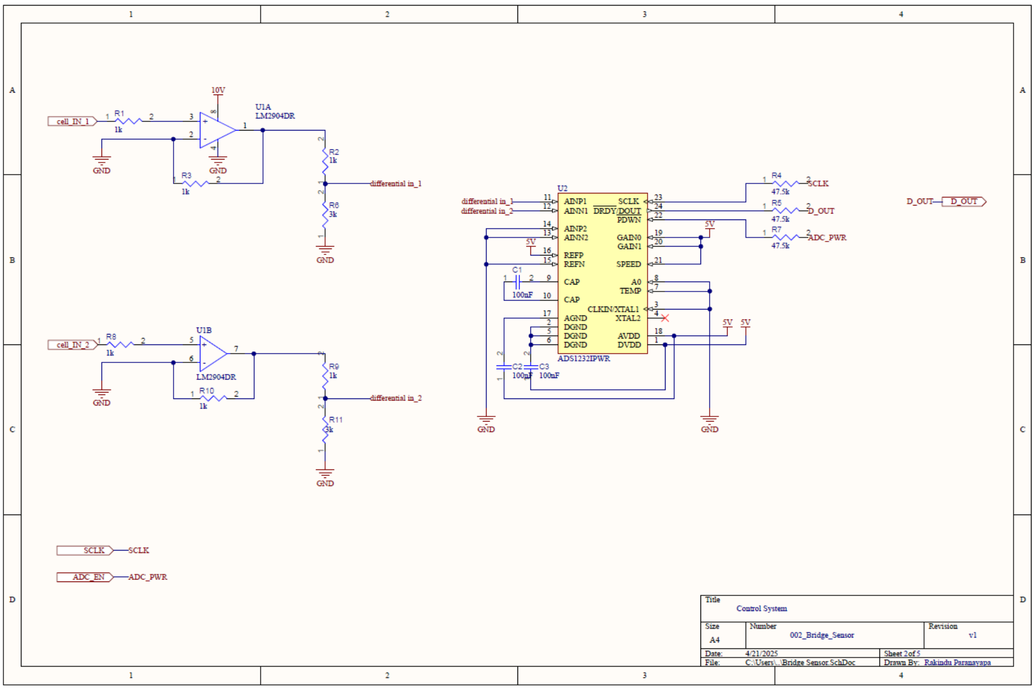
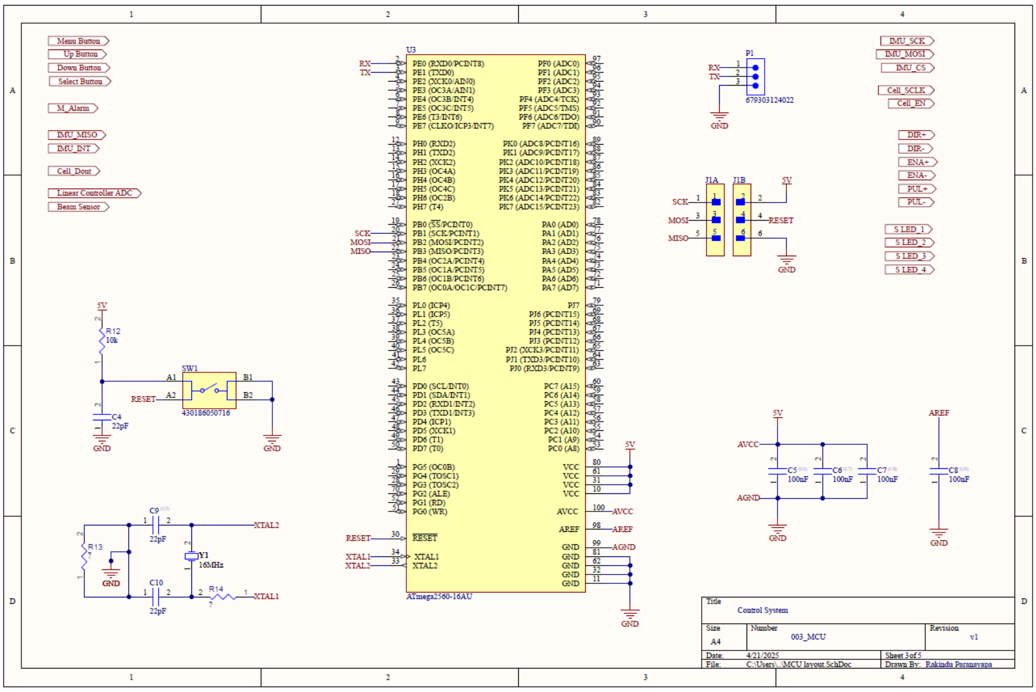


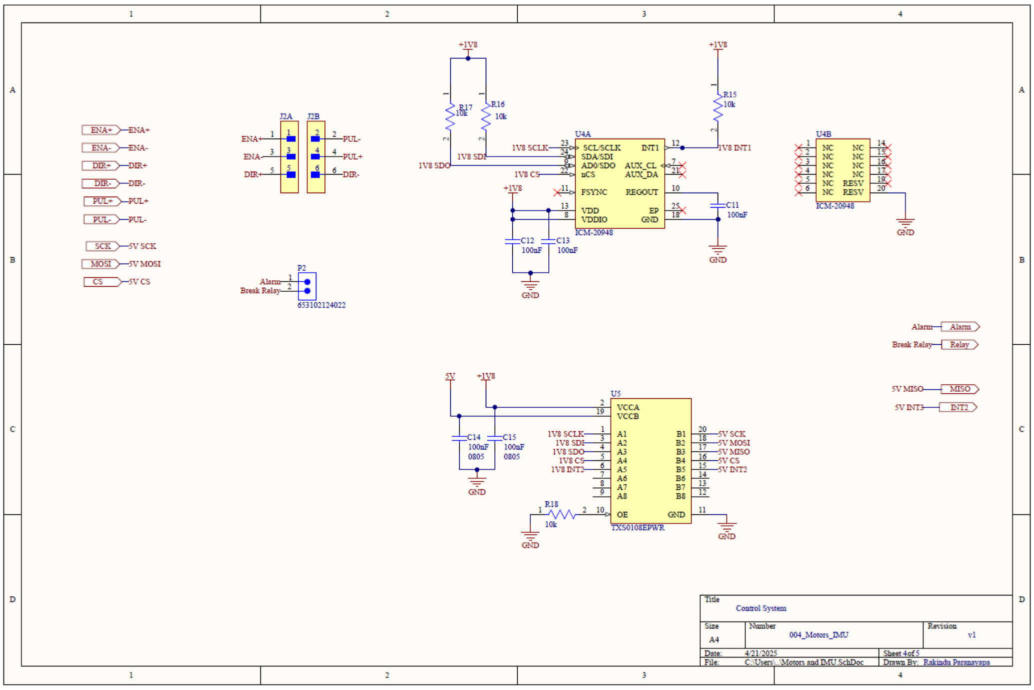
Figure 8: Flow Chart

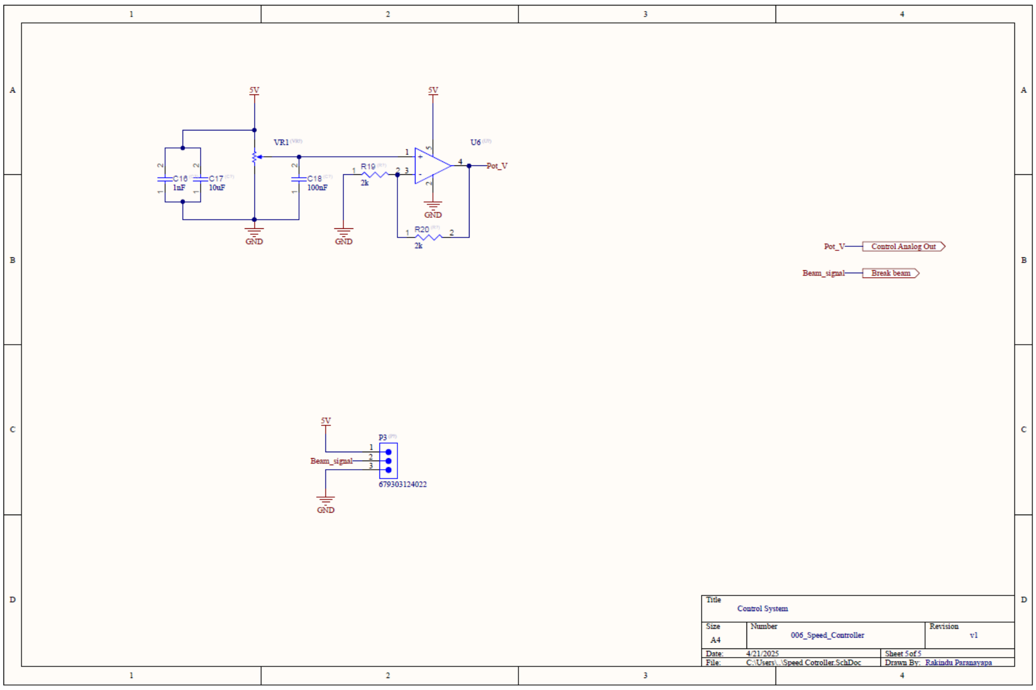
5.5 Schematic Design






Control System
003_MCU
ATmega2560-16AU
4/21/2025
Sheet 3 of 5
Drawn By: Rakindu Paranavapa


Control System
004_Motors_IMU
ICM-20948
TXS0108EPWR
4/21/2025
Sheet 4 of 5
Drawn By: Rakindu Paranavapa


5V
VR1
C16
1nF
C17
10uF
C18
100nF
GND
R19
2k
R20
2k
U6
Pot_V
Pot_V
Control Analog Out
Beam_signal
Break beam
P3
Beam_signal
679303124022
Title
Control System
Size
A4
Number
006_Speed_Controller
Revision
v1
Date: 4/21/2025
Sheet 5of 5
File: C:\Users\..\Speed Cotroller.SchDoc
Drawn By: Rakindu Paranayapa

6. Appendix

6.1 Referenced YouTube Videos for User Observation

1. Indeva Group. Industrial Manipulators – Liftronic Easy. Available: https://www.indevagroup.com/category/industrial-manipulators-2/liftronic-easy/
2. Ergonomic Partners. *Zero Gravity Lifting Device Demonstration*. YouTube. Available: https://www.youtube.com/watch?v=PXRSgoT8lzQ
3. Ergonomic Partners. *Zero Gravity Arm – Load Balancing Lifting Device*. YouTube. Available: https://www.youtube.com/watch?v=3nbhKaFVKvg
4. Ergonomic Partners. *Zero Gravity Lifting with Intelligent Assist Devices*. YouTube. Available: https://www.youtube.com/watch?v=fyK2Mw_ho10
5. Hoist UK. Industrial Lifting Solutions. Available: https://www.hoistuk.com/products/industrial/
6. ON Lifting. Electric Hoist Products. Available: https://www.onlifting.com/Electric-Hoist-pl44855387.html
7. Kundel Industries. Custom Lifting Devices – Arm Units. Available: https://kundel.com/products/custom-lifting-devices/arm-units/