UNIVERSIDAD DE OVIEDO

CENTRO INTERNACIONAL DE POSTGRADO

MASTER EN INGENIERÍA MECATRÓNICA

TRABAJO FIN DE MÁSTER

Autonomous pick & place robot for electronic component drawers in their shelves

Md. Shafiqul Islam

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ABSTRACT

This thesis presents the design and development of an autonomous pick-and-place robot system for electrical component drawers on their shelves. The main focus is designing a gripping system that is capable of accurately picking drawers from electrical component shelves and placing them in specified places with precision. To achieve a successful pick and place operation, the thesis carries a combination of mechanical design, electrical design, and advanced control algorithms. For controlling the movement of the vehicle and automating, a user-friendly interface has been developed. After achieving the design and manufacturing phase, the hardware and software integration, part has been done. The system's functionality, performance and accuracy were evaluated and optimized through a series of experimental tests and analysis. The study also focuses on finding the development issues and examines alternative solution to improve the capabilities and robustness for successful automation of the system.

KEYWORDS

Pick and Place Robot – Gripper Design – Drawer Grasping – Robotic Automation

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1. INTRODUCTION

This introductory chapter focus on the background of autonomous pick and place robots, delving into their background, the driving motivations behind this research, and the objectives we aim to achieve through the course of this master's thesis.

1.1. Background

Advanced robotic systems known as autonomous pick and place robots have been developed to carry out activities like picking up items from one area and placing them in another without the assistance of a human. These robots are frequently used in manufacturing, logistics, warehouses, and other sectors to automate processes, boost productivity, and lower labor costs. Since these robots are autonomous, they can work without continual human supervision, which increases productivity and consistency in repeated activities [1].

These robots can sense their environment, devise efficient instruction, grasp things of all shapes and sizes, and carry out accurate movements throughout the pick and place process thanks to a variety of sensors, actuators, and control systems that are accessible to them. The integration of computer vision, machine learning, and robotics technologies is crucial for enabling these robots to adapt to different scenarios, handle object variations, and make real-time decisions [2].

The pick and place robot market has shown remarkable growth trends. Valued at USD 3.0 billion in 2022, this market is projected to surge to USD 7.4 billion by 2032, experiencing a robust compound annual growth rate (CAGR) of 9.6% between 2022 and 2032. The global expansion of the pick and place robot market is chiefly powered by escalating demands for automation across diverse sectors like food and beverage, automotive, and electronics. These robots specialize in repetitive tasks such as sorting, packaging, and assembling, contributing to enhanced productivity and reduced human errors. The upsurge in Industry 4.0 and Internet of Things (IoT) technologies further propels market growth [3].

In recent robotics research, several autonomous picking systems have been developed for various applications. These systems integrate perception, planning, and control strategies to successfully grasp and manipulate objects. Challenges such as occlusions and fragility have been recognized, motivating further exploration. One study focuses on e-commerce warehouse tasks, using lightweight robots and modular software for flexible picking. Another research effort introduces a cucumber harvesting robot, detailing hardware, software, and the need for improved image processing. A mobile dual-arm robot is proposed for warehouse order picking, showcasing adaptability and accuracy. Lastly, an efficient strategy-based approach is presented for item picking in e-commerce shelves, emphasizing rapid planning and diverse item handling [4-8].

1.2. Motivation

At the University of Oviedo, there are several labs for experimental studies. Almost at every lab there are electrical components drawers and it’s often necessary to pick some of the components and place at the right place. The idea is to develop an autonomous mobile robot that can automate this task as a master’s thesis project.

Electronic component drawers are storage solutions designed to organize and store small electronic parts, crucial for efficient electronics assembly and repair. They feature divided compartments for categorization and accessibility. Valuable in inventory management, they expedite locating and accessing specific components. Beneficial for electronics manufacturing, repair, and prototyping, these drawers enhance efficiency by reducing search time. They counteract component loss and accommodate small workspaces through optimized space utilization. As electronics industry growth, miniaturization, DIY (do it yourself) projects, repair, manufacturing, and education needs surge, the demand for these drawers continues to rise.

The objective to be achieved at the end of the master's thesis is to successfully design, develop, and implement an autonomous pick and place robot tailored for the electronic component drawers within their shelves. This involves creating a functional robotic base with an elevating arm and gripper capable of extracting desired drawers from electronic component shelves and placing them on a user's table, and returning them to the shelf. The focus lies on accomplishing precise mechanical design, particularly designing a gripper that can effectively pick the drawers. Furthermore, achieving seamless coordination of movements during the extraction process and integrating the necessary electronics for autonomous operation are key components of this objective.

1.3. *Objective and Scope*

The main objective of the master's thesis is to successfully solve the problems of picking and placing the electrical component drawers. The main idea is to study the background of this type of solution and choose the ideal one. The goal is not designing a full prototype but the conceptual design which solves the problem and also ensure that the components are available in the lab. The movement of the vehicle, elevating arm and gripper will be evaluated by a manual user interface. The full automation of movement and detection of drawer is not the focus as lack of necessary component. The specific objectives to be achieved of the proposed solution are the following:

- ⇨ Design a mechanical gripper that can grab and open the electronic component drawers from the shelves.
- ⇨ Improvement of an existing elevating arm that can reach the gripper to the height of the shelves.
- ⇨ Adjustment of an existing robotic base which can move to the shelves, picks the component drawers and place it to a specific place inside the laboratory.
- ⇨ Create an application software with a user interface that can control the vehicle from a short distance via Wi-Fi communication.
- ⇨ Control the movements of the vehicle, of the elevating arm and of the gripper
- ⇨ Implement an automated logic to evaluate the picking and positioning process.

2. LITERATURE REVIEW

This chapter focus on the background studies for autonomous pick and place robot. It briefly discusses the current scenario of warehouse automation, the existing solutions that are available for pick and place robot, the relevant technologies and finally what are the main challenges that autonomous robotic picking systems face.

2.1. Overview of Robotic Manipulation in Warehouse Automation:

Robotic manipulation is transforming warehouse automation by allowing for the efficient handling, sorting, and transportation of various items. The incorporation of manipulation skills inside warehouse operations has resulted in a new era of efficiency and productivity, due to the rapid growth of robot technologies.

Warehouse automation, robotic manipulation, such as the one shown in Figure 1, comprises the use of robotic arms, grippers, and complex control systems to accomplish challenging tasks such as picking, placing, and moving products of various sizes and shapes. This technology has proven very useful in optimizing order fulfillment procedures, minimizing human intervention, and lowering operating expenses.

Figure 1 - Typical robotic manipulation in warehouse automation [9]

Robotic manipulation systems are outfitted with a variety of sensors and perceptual technologies that enable them to sense and analyze their surroundings. These sensors provide critical data for accurate item detection, position, and orientation, allowing for precision manipulation even in cluttered or dynamic situations.

One of the primary difficulties addressed by robotic manipulation in warehouse automation is the efficient and dependable picking of objects. The vast range of products present in warehouses adds to the task's difficulty. These robots must be able to handle things of various forms, sizes, and materials, adjusting their grip approaches accordingly.

The incorporation of artificial intelligence, machine learning, and computer vision improves the abilities of robotic manipulation systems even further. These innovations allow robots to acquire knowledge and adapt to new environments, increasing their accuracy and efficiency over time. Furthermore, collaborative and cooperative manipulation methodologies allow robots to work alongside human operators, optimizing warehouse operations even further.

Robotic manipulation technologies are not only being used in typical warehouses but also in e-commerce and fulfillment centers. These systems provide a scalable solution to address the growing demand for speedier order processing and precise delivery [10, 11].

2.2. Existing Solutions for Pick and Place Systems:

Existing pick and place system solutions include a wide range of technologies and methodologies for automating object manipulation activities. These systems are critical in industries like manufacturing, shipping, and warehousing, where effective object handling is critical for optimizing operations and decreasing manual labor. Some notable solutions include:

Industrial Robots: Pick and place activities have long been performed by conventional industrial robots equipped with automated arms and end-effectors. These robots are frequently designed with certain trajectories and motions to pick up and place objects precisely. They are commonly used in production contexts for tasks like product assembly and sorting.

Delta Robots: Delta robots, also known as parallel robots, are distinguished by their distinctive design, which has numerous limbs connected to a central base. These robots excel at picking and placing objects on conveyor belts or assembling electrical components, which need high-speed and precision pick and place actions.

SCARA Robots: SCARA (Selective Compliance Assembly Robot Arm) robots are effective in sectors that require fast and precise horizontal pick and place activities. Their robust structure and efficient action make them suitable for activities such as placing components on circuit boards or packing things.

Collaborative Robots (Cobots): Cobots are robots that perform pick-and-place tasks alongside people to increase productivity and safety. Cobots can detect human presence and change their actions accordingly because they are equipped with sensors and safety measures, making them suited for tasks like product loading and unloading in shared workspaces.

Vision-Guided Systems: These systems use computer vision technology to recognize objects, find them, and develop effective grasping techniques. By integrating cameras, image processing algorithms, and artificial intelligence, vision-guided systems increase precision and adaptability in pick and place activities.

Gripping Technologies: Advances in gripper design have resulted in the creation of adaptable grippers that can adapt to a variety of item geometries. Grippers using suction cups, mechanical fingers, soft robotics or hoover systems may firmly grip and manipulate items with varying surface characteristics.

Machine Learning and Artificial Intelligence: Artificial intelligence is important in optimizing pick and place systems. Based on past data and real-time input, machine learning algorithms can be trained to recognize items, forecast their movements, and optimize the pick and place process.

Sensor Integration: Sensors such as force/torque sensors and tactile sensors allow robots to perceive and change the force and pressure of their grasps. This is particularly true when working with sensitive or fragile objects.

Hybrid Systems: Some systems mix several types of robots or techniques to improve performance. Integrating a robot arm with a conveyor belt system, for example, can result in efficient pick and place processes in high-throughput environments.

Customized Solutions: Industries with specific demands frequently design customized pick and place solutions. To get the best outcomes, these solutions may entail the integration of numerous technologies, such as sophisticated grippers, vision systems, and motion control.

2.2.1. *RECENT RESEARCH FOR PICK AND PLACE SYSTEMS*

This section delves into the latest research related to pick and place systems. We will explore recent studies and investigations that are closely connected to the subject matter of our master's thesis. These findings provide valuable insights into the advancements and challenges within the field of pick and place robotics, offering a foundation for our own research.

The paper "DoraPicker: An Autonomous Picking System for General Objects" by Hao Zhang et al. aims to introduce an autonomous picking system, DoraPicker (see Figure 2), designed to effectively retrieve and manipulate diverse objects in unstructured environments. Through a combination of perception, planning, and control strategies, the system demonstrates successful object grasping and picking across various scenarios. The integration of visual perception, 3D object reconstruction, grasp planning, and real-time control contributes to its accurate and efficient performance. While showcasing its robustness, the paper acknowledges challenges in scenarios with occluded or partially visible objects. The study's scope primarily centers on object picking, with potential for further exploration of handling fragile or deformable items and assessing its scalability and effectiveness in dynamic, cluttered environments [4].

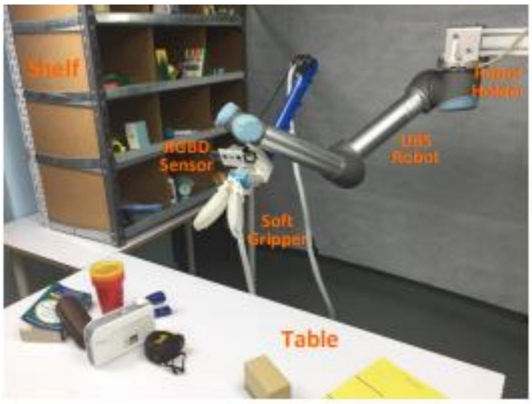

Figure 2 - The DoraPicker autonomous picking system [4]

According to C. Liang et al. an autonomous pick-and-place robotic system designed to handle the task of picking items in e-commerce fulfillment warehouses. The system features a lightweight robot manipulator equipped with stereo cameras and modular software modules. Experimental tests, conducted using a prototype, demonstrate the system's flexibility and robustness in picking regularly-shaped grocery products. Future plans involve enhancing perception algorithms, incorporating impedance control for diverse objects, and developing versatile grippers to expand its grasping capabilities [5].

An autonomous cucumber harvesting robot for greenhouse applications has been studied by E.J. VAN HENTEN et al. The study outlines the working environment, logistical considerations, and design specifications of the robot. It highlights the utilization of a high-wire cultivation system to enhance fruit accessibility. The paper comprehensively details the hardware and software components of the robot, encompassing autonomous vehicle control, manipulator functionality, end-effector design, vision systems, and collision-free motion planning. While successful field tests demonstrated the robot's ability to harvest cucumbers with an 80% success rate, the paper acknowledges the need for further advancements in 3D image processing, object identification, and motion planning to achieve faster picking speeds and improved co-ordination [6].

A mobile dual-arm robot has been suggested by Nobutaka Kimura et al. for automated order picking in warehouses with a variety of products. The authors introduce a comprehensive system that employs two robotic arms and mobile capabilities to efficiently handle various types of items. The findings showcase the robot's capability to navigate through a warehouse, identify objects, and execute picking tasks with high accuracy and adaptability. This research contributes to enhancing warehouse automation by addressing the challenges posed by the diversity of products and optimizing order fulfillment processes [7]

Haifei Zhu. et al. introduces an effective and efficient strategy-based planning approach for robotic item picking from shelves in e-commerce warehouses, addressing challenges posed by diverse items and environmental constraints. Utilizing a gripper with multiple securing methods, the authors model differentiated picking strategies as primitives and propose a strategy generator and evaluator for planning. Experiments demonstrate the robot's capability to generate feasible strategies within 2ms and achieve a 68% success rate in picking daily items from shelves. The paper contributes a rapid planning method for confined environments, while acknowledging the need for refining strategies and testing under varied conditions [8].

Overall, the landscape of existing solutions for pick and place systems is dynamic, driven by advancements in robotics, automation, and AI technologies. The choice of solution depends on factors like application requirements, object characteristics, throughput, accuracy, and cost-effectiveness.

2.3. Relevant Technologies:

There are different technologies used in the automation of pick and place operation. The possible technologies like gripper design, rover types, linear guides, robotic arms, sensors and electronics will be discussed in this section.

2.3.1. *GRIPPER DESIGNS*

Pick and place systems rely heavily on gripper designs since they dictate how things are gripped and moved. There are several varieties of grippers, each designed to handle different object forms, sizes, weights, and materials. Here are some examples of popular gripper designs:

Parallel Jaw Gripper: This gripper type has two conflicting jaws that move in parallel, shows in Figure 3. It's best for holding objects with consistent shapes, such as boxes or cylindrical objects. Parallel jaw grippers are versatile and can be used in many different situations.

Figure 3 - Parallel Jaw Gripper

Angular Gripper: Jaws on angular grippers can move in either an angular or radial direction. When picking up items from the side or when space restrictions prevent a direct approach, they are useful.

Angled grippers are frequently used for tasks like inserting parts into constrained spaces. Its shape can be visualized in Figure 4.

Figure 4 - Angular gripper

Three-Fingered Gripper: To mimic the human hand, three-fingered grippers have three moving fingers. This design, as shown in **Error! Reference source not found.**, enables a more flexible grip and improved flexibility when handling things of erratic shapes. Three-finger grippers are frequently used in both research and business.

Figure 5 - Three-Fingered Gripper

Two-Fingered Gripper: Like three-finger grippers, two-finger grippers (**Error! Reference source not found.**) have two movable fingers. They are typically used to handle objects with somewhat regular shapes because of their simpler construction.

Figure 6 - Two-Fingered Gripper

Soft Gripper: Soft grippers shows in Figure 7, are made of elastic materials that may mold to the shape of the thing being held. They work well for items that are delicate or have odd shapes, such as fruits or linens. Soft grippers are less likely to harm delicate items and can give different holding forces.

Figure 7 - Soft Gripper

Vacuum Gripper: Vacuum grippers (Figure 8) employ suction to hold objects in place. They work particularly well with objects having flat surfaces, such paper sheets or glass panels. In the fields of packing, printing, and electronics, vacuum grippers are frequently used.

Figure 8 - Vacuum Gripper

Magnetic Gripper: Electromagnetic fields are used by magnetic grippers to draw in and retain ferromagnetic objects. They are suitable for steel or iron objects. When alternative grasping techniques may be ineffectual, magnetic grippers are used. A magnetic gripper is displayed in Figure 9.

Figure 9 - Magnetic Gripper

Adhesive Gripper: Objects having adhesive pads or surfaces are grasped by adhesive grippers. They can work with objects of all sizes and shapes because they are versatile. Adhesive gripper shows in Figure 10, are useful when a solid grasp is needed on uneven or porous surfaces.

Figure 10 - Adhesive Gripper

Pneumatic Gripper: Compressed air is used by pneumatic grippers to open and close their jaws. They are widely used in industrial settings where quick and accurate grabbing is required.

Pneumatic grippers show in Figure 11, have a high force capacity and are appropriate for heavy things.

Figure 11 - Pneumatic Gripper

Hybrid Gripper: To achieve optimal performance, hybrid gripper shows in Figure 12, integrate features from many gripper kinds. A gripper, for example, could combine soft and pneumatic parts to handle fragile things while applying controlled force.

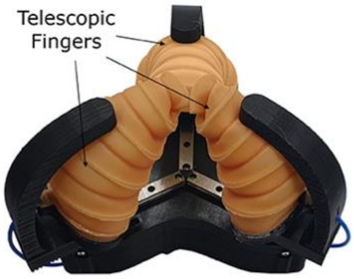

Figure 12 - Three-fingered Hybrid Gripper

Table 1 - Comparison between different types of grippers for gripping system

Gripper Design	Pros	Cons
Parallel Jaw Gripper	Versatile, suitable for uniform objects	Limited adaptability for irregular shapes
Angular Gripper	Side gripping, useful in tight spaces	Limited to certain orientations
Three-Fingered Gripper	Flexible, adaptive grip	Complex design, higher cost
Two-Fingered Gripper	Simple design, suitable for uniform objects	Limited adaptability for irregular shapes
Soft Gripper	Conforms to object shape, good for delicate items	Lower gripping force, durability concerns
Vacuum Gripper	Suitable for flat surfaces, non-contact	Limited to objects with flat surfaces
Magnetic Gripper	Works with ferromagnetic objects	Limited to objects with specific materials
Adhesive Gripper	Versatile, good for irregular surfaces	Adhesive wear, cleanliness concerns
Pneumatic Gripper	Quick and precise, high gripping force	Requires compressed air supply
Hybrid Gripper	Customizable to specific needs	Design complexity, potential cost

The right gripper design can be determined by the needs of the given application, such as the sort of objects being handled, the required gripping force, the available space, and the desired amount of adaptability. With developments in materials, sensors, and robotics, gripper designs continue to evolve, resulting in more efficient and adaptable pick and place systems [12, 13].

2.3.2. ROVERS TYPE

Pick and place rover designs vary, with each having a distinct wheel type to optimize mobility and maneuverability in diverse conditions. The type of wheel used is determined by criteria such as topography, payload capacity, traction, and intended range of motion. The following are some of the most frequent wheel types used in rovers for pick and place activities:

Wheeled Rovers: There are different types of wheeled rovers. These are,

- Standard Wheels: These are typical circular wheels that move easily and steadily on level, uniform terrain. They are perfect for warehouses and factories with smooth flooring because they are suitable for interior situations with smooth surfaces. Figure 13 shows standard wheels.

Figure 13 - Standard wheels for mobile robot

- Omni Wheels: Multiple rollers are attached at an angle around the perimeter of an omni wheel. They allow the rover to move in any direction, even diagonally and sideways. Omni wheels, as shown in **Error! Reference source not found.**, enhance maneuverability in constrained spaces or around tight corners.

Figure 14 - Omni Wheels

- Mecanum Wheels: Mecanum wheels have rollers that are offset from the main axis of rotation. Mecanum wheels allow a rover to move in any direction and even rotate in place by individually controlling each wheel's movement. Mecanum wheels are perfect for intricate maneuvers and confined spaces. Figure 15 shows mecanum wheels.

Figure 15 - Mecanum Wheels

Tracked Rovers: Tracked rovers are ideal for rough terrain which provides as much traction as possible and the weight of the rover is being distributed evenly. The different types of tracked rovers are,

- Tank Tracks: The continuous tracks that surround the clusters of wheels on either side of the rover make up the tank tracks. Figure 16 shows an example of tank tracks. They are perfect for use outside or in places with obstacles since they provide exceptional traction and stability on rocky, uneven terrain.

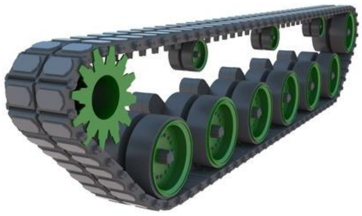

Figure 16 - Tank Tracks

- Lunar Wheels: Lunar wheels have a distinctive design that enables them to deform and adjust to uneven surfaces thanks to flexible spokes. Figure 17 shows lunar wheels. Because they more evenly distribute the rover's weight and lessen the possibility of getting stuck, they are perfect for rocky or uneven terrains.

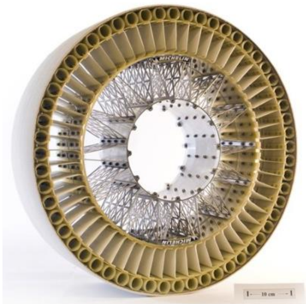

Figure 17 - Lunar Wheels

Legged Rovers:

- Walking Legs: Legged rovers can traverse a wide range of terrain since they have multiple walking legs. Figure 18 shows walking legged rovers. They are suitable for uneven and unexpected surfaces since they can move over obstacles and negotiate challenging conditions.

Figure 18 - Walking Legged Rovers

Hybrid Rovers:

- Combination of Wheels and Legs: Some rovers have both wheel and leg mechanisms, which they use to achieve a balance between stability and agility. Figure 19 shows Hybrid Rovers. Such hybrid systems can switch between flat-surface wheel-based movement and challenging terrain leg-based movement.

Figure 19 - Hybrid Rovers

Caster Wheels:

- Caster Wheels: Caster wheels are single wheels that swivel on a mechanism. They rotate 360 degrees and are frequently used as support wheels in conjunction with normal or omni wheels. Caster wheels improve stability and maneuverability. Figure 20 shows standard wheels.

Figure 20 - Caster Wheels

Table 2 - Comparison of various types of rovers for pick and place operations

Rover Type	Pros	Cons
Standard Wheels	Simple, stable movement	Limited maneuverability
Omni Wheels	Superior maneuverability	Less stable, less efficient on smooth surfaces
Mecanum Wheels	Excellent maneuverability, omnidirectional	Complex control, higher cost

Caster Wheels	360-degree rotation, enhances maneuverability	Limited weight capacity
Hybrid (Wheels+Legs)	Versatility, balance between stability and adaptability	Complex design, potential complexity
Tracked (Tank Tracks)	Excellent traction, stability	Limited maneuverability
Lunar Wheels	Adaptable to uneven surfaces	Specialized design, potential complexity
Legged (Walking Legs)	Adaptability to various terrains	Complex mechanical design

The type of wheel used is determined by the environment in which the rover will operate as well as the requirements of the pick and place operations. Standard or omni wheels may be sufficient for indoor areas with smooth floors. Tank tracks or legged mechanisms may be more appropriate for outdoor terrains with obstacles. Because of the adaptability of hybrid designs, rovers can adapt to a variety of situations, making them appropriate for a wide range of pick and place applications.

2.3.3. *LINEAR GUIDES*

Linear guides are critical components in pick-and-place robotics because they ensure the robot's moving elements move precisely and smoothly. There are various kinds of linear guides that are regularly used:

Ball Screw Guides: To transform rotary motion into linear motion, ball screws are utilized. They are made up of a screw shaft and a ball nut containing recirculating ball bearings. This type of guide has great accuracy, minimal friction, and a high weight-carrying capacity, making it ideal for applications that require high precision and repeatability. Figure 21 shows Ball Screw Guides.

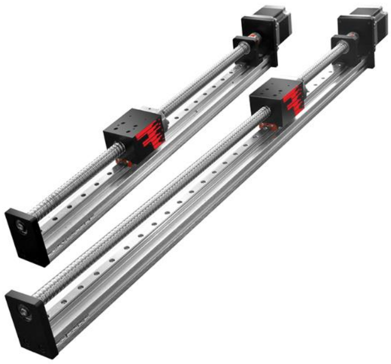

Figure 21 - Ball Screw Guides

Linear Rail Guides: Linear rail guides are made up of a rail and a carriage, and are also known as linear guide rails or linear guide systems. Rollers and other rolling components of the carriage move smoothly along the rail. For increased load capacity and stability, this design, which offers smooth and precise linear motion, is usually employed with many carriages. Figure 22 shows Linear Rail Guides

Figure 22 - Linear Rail Guides

Profiled Rail Guides: Like linear rail guides, profiled rail guides offer increased rigidity and load capacity. For exceptional accuracy and fluid movement, they are constructed with finely machined rails and blocks. They are widely used in industrial automation where there are heavy weights and challenging environments. Figure 23 shows the Profiled Rail Guides

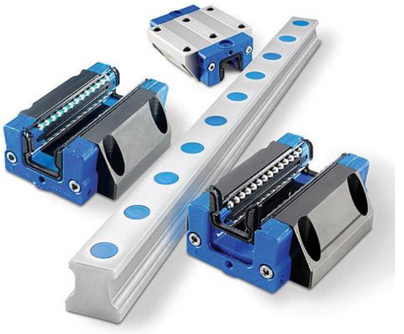

Figure 23 - Profiled Rail Guides

Crossed Roller Guides: In crossed roller guides, cylindrical rollers are arranged in a crossing pattern between two V-shaped channels. High levels of rigidity, accuracy, and compactness are present in this design. They are appropriate for applications that need for precise movement in a small space. Figure 24 shows Crossed Roller Guides

Figure 24 - Crossed Roller Guides

Linear Slide Guides: The components that make up linear slide guides slide along a straight track. They come in a variety of designs, such as basic sliding surfaces and ball-bearing slides. They are suitable for applications requiring moderate precision and are less complex than other types of guides. Figure 25 shows Linear Slide Guides

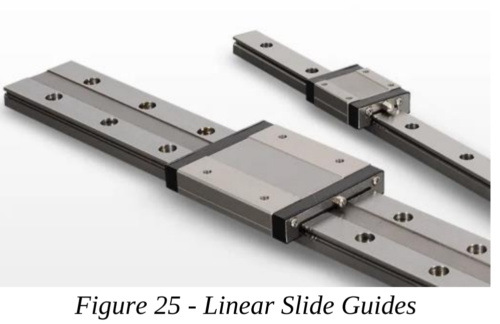

Figure 25 - Linear Slide Guides

Cam Roller Guides: Cam roller guides use curved rail profiles and cylindrical rollers. They are intended for applications requiring smooth motion and fast operation. Cam roller guides are frequently employed in situations requiring continuous linear motion, such as conveyor systems. Figure 26 shows Cam Roller Guides.

Figure 26 - Cam Roller Guides

Table 3 - Comparison of various types of linear guides for adjusting the height

Linear Guide Type	Pros	Cons
Ball Screw Guides	High accuracy, low friction, good load capacity	More complex design, potentially higher cost
Linear Rail Guides	Smooth and precise motion, multiple carriages possible	Limited load capacity compared to some others
Profiled Rail Guides	High load capacity, rigidity, and accuracy	More complex design, potentially higher cost
Crossed Roller Guides	High rigidity, accuracy, and compactness	Limited load capacity for larger robots
Linear Slide Guides	Simplicity, moderate precision	Limited load capacity and precision
Cam Roller Guides	Smooth motion, high-speed operation	Limited to specific applications

The linear guide used by a pick-and-place robot is determined by criteria such as necessary precision, load capacity, speed, available space, and environmental conditions. Each type of guide has pros and cons, therefore thoughtful consideration is required to ensure the robot's maximum performance.

2.3.4. *ROBOTIC ARMS*

Robotic arms are mechanical devices that imitate the actions of the human arm. They are made up of numerous linked segments that are frequently operated by motors or other mechanical mechanisms. The robotic arm of a pick-and-place robot is responsible for precisely and accurately grasping objects from one position and depositing them in another.

Pick-and-place robot arms exist in a variety of configurations, including SCARA, articulated, delta, and Cartesian. The arm design chosen is determined by criteria such as reach, cargo capacity, workspace area, and needed dexterity.

2.3.5. *SENSORS*

Sensors are essential parts that provide feedback to the robot about its environment. For precise object detection, position sensing, and collision avoidance in a pick-and-place robot, sensors are essential. Here are a few instances of typical pick-and-place robot sensors:

Vision Systems: Cameras and image processing algorithms are used to detect items visually, catalog their traits, and determine where they should be placed. This enables the robot to locate objects, position itself correctly, and make accurate pickups and placements.

Proximity Sensors: The presence or absence of objects within their detecting range is detected by ultrasonic, capacitive, and inductive proximity sensors. They are commonly used for object positioning and detection.

Force/Torque Sensors: These sensors track the forces and torques applied to the robot's end-effector during contacts with objects. Using this information, the robot can adjust its grasp and pressure to handle objects delicately or apply consistent pressure.

Encoder Sensors: Encoders are used to provide the rotational position of the robot's joints and actuators. For controlling the robot's movements and achieving the appropriate locations, this information is essential.

Limit Switches: The end points of the robot's mobility range are located using limit switches. They help to ensure safe operation and prevent overtravel.

2.3.6. *ELECTRONICS*

The electronics of a pick-and-place robot include the control system and the interface between sensors, actuators, and the central processing unit of the machine. The crucial electronic parts are listed as follows:

Microcontroller/PLC: The brain of the robot's control system is the microprocessor or programmable logic controller (PLC), which processes sensory data and generates commands for the actuators to carry out desired motions.

Motor Drivers: Motor drivers control the speed and rotation direction of the robot's motors by supplying the necessary current and voltage.

Power Distribution: Electronics control how much power is distributed to different parts, ensuring proper operation and preventing excessive damage.

Communication Interfaces: The robot can interact with outside systems or operators and receive commands by using communication interfaces like Ethernet, USB, or wireless connections.

Control Algorithms: These algorithms determine the robot's movements based on sensor feedback and predetermined commands, ensuring precise pick-and-place operations while taking path planning, collision avoidance, and trajectory optimization into account.

In summary, the integration of a suitable robotic arm, numerous sensors for environmental awareness, and a well-designed electronic control system that coordinates and executes precise and effective pick-and-place activities are all necessary for a pick-and-place robot to be effective.

2.4. *Challenges in Autonomous Robotic Picking Systems:*

In order for autonomous robotic picking systems to perform successfully and effectively, a variety of problems must be solved. Here are some of the major challenges:

Object Recognition and Perception: It is difficult to accurately detect and recognise objects in busy and diverse settings. Objects can vary in shape, size, colour, and texture, necessitating the development of strong perception systems capable of handling these variances and providing reliable object detection.

Grasping and Manipulation: It is a difficult effort to design grippers and end-effectors that can reliably grasp a large range of items with varied shapes, sizes, and materials. To ensure that the robot can move objects without hurting or dropping them, complex grasp planning and control algorithms are required.

Path Planning and Collision Avoidance: Navigating the robot arm in obstructed situations necessitates excellent path planning and collision avoidance algorithms. This is essential for avoiding collisions with both static and dynamic impediments, as well as optimizing the robot's trajectory for efficient and safe mobility.

Dexterity and Agility: It is difficult to develop the dexterity and agility required to handle delicate things or perform intricate tasks. Research into developing robots that can mimic human-like movements while preserving precision and efficiency is continuing.

Variability in Objects: Objects in real-world contexts frequently have unpredictable poses, orientations, and positions. To achieve successful pick-and-place operations, autonomous picking systems must be adaptive and capable of dealing with this fluctuation.

Multi-Object Handling: Picking and placing many objects in a single action necessitates sophisticated planning and coordination algorithms. Choosing the sequence of choosing, optimizing trajectories, and avoiding collisions between objects are all difficult issues.

Sensory Noise and Uncertainty: Perception sensors are subject to noise, variations in lighting, and other environmental conditions that can induce ambiguity. It is critical for reliable operation to develop algorithms that can filter out noise and deal with uncertainty.

Integration with Production Lines: Autonomous picking systems must frequently connect with current manufacturing lines and procedures. It might be difficult to ensure compatibility, synchronization, and minimal disturbance to existing operations.

Scalability and Flexibility: Adapting robotic picking systems to handle a wide variety of products and production scenarios requires scalability and flexibility in both hardware and software. Designing systems that can be easily configured and reconfigured is important.
Human-Robot Interaction: Collaborative environments where humans and robots work together raise challenges related to safety, communication, and coordination. Developing intuitive interfaces and ensuring safe interactions are important considerations.

Addressing these challenges requires a combination of advanced robotics, computer vision, machine learning, and control techniques. As technology continues to evolve, researchers and engineers are making significant strides in overcoming these obstacles and enabling more capable and efficient autonomous robotic picking systems [14, 15].

3. CONCEPTUAL DESIGN OF THE PROTOTYPE

This chapter is focus on the initial thought how the design will be done and finally how it reaches the goal.

Different existing solutions for pick and place robot have been discussed at the background study. Most of the existing solutions are more or less designed for the warehouse automation purpose. In the background study there is no direct match to the problem have been discussed here. In this specific master's thesis, the task is to develop a prototype to open drawers from specific electrical component shelves, then pick and place it to specific place.

Figure 27 - Electrical component shelves [16]

Figure 27 shows the typical electrical component shelves used for this master’s thesis. The electrical component shelves we chose for the MASTER’S THESIS is 30 drawers’ shelves. The dimensions of the self are 470mm (height), 270mm (width) and 130mm (depth). There are three different sizes of drawers. The dimensions are given below,

Table 4 - Specification of the electrical component shelves

Storage Drawer Size (Height*Width*Depth)	Quantity of Storage Drawer	Each Drawer Capacity
35mm x 60mm x 105mm	1 x 24	3kg
35mm x 120mm x 105mm	1 x 4	
35mm x 260mm x 105mm	1 x 2	

Normally, the electrical component shelves are kept on tables or on other shelves inside the labs. The tables and shelves are always in a human-reachable position. Normally, the table height is 70-75cm and the height of the shelves is more or less 170cm. So, the elevating arm we will require for the prototype can change position in between these heights. It’s also required to have a smooth driving vehicle which can be driven easily to different positions and even corners of the lab to reach the table or shelves to pick and place the drawers. Figure 28 shows the typical position of the electrical component shelves inside the lab.

Figure 28 - Typical Position of the shelves in the lab

For picking and placing the drawers the concept was to design and develop a rover. Where there is a Gripper to grip the drawers and a linear lifting system which helps to reach the height of the shelves. Then there is a base which will move the gripper to different places.

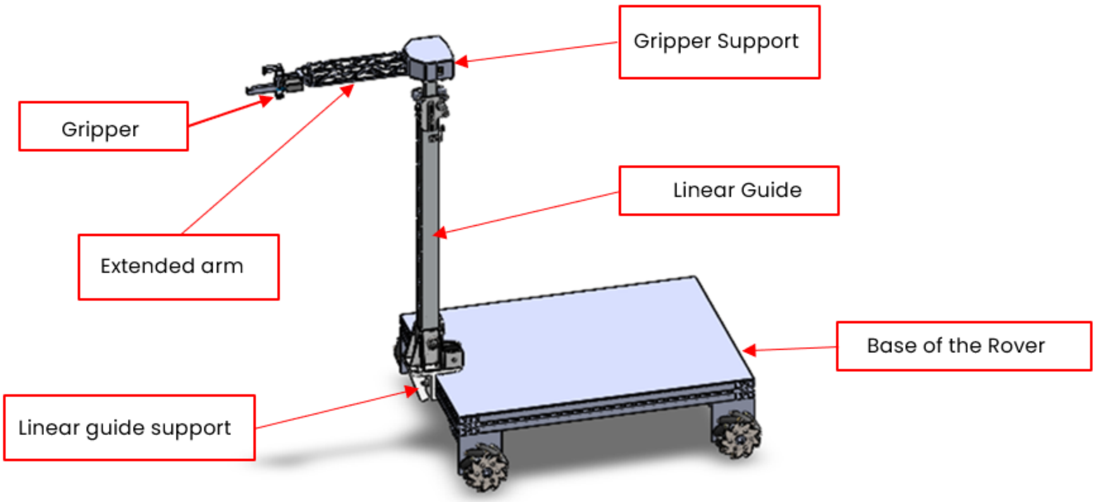

Figure 29 - The conceptual design of the rover

Figure 29 shows the conceptual design of the rover. At the bottom there is the base connected with motor and wheels which supports the whole vehicle and holds the necessary components for the rover. Then at the top of the base the linear guide is fixed. And for that reason, a part has been designed to support the linear guide. A box structured gripper support is designed to hold the gripper with the extended arm. This gripper support is mounted at the top of the linear guide. The reason for box structure is because to keep the PCB for the gripper inside the box. At the top end there is the gripper. But for gripping the drawers it is needed to reach the gripper inside the shelves. For that the idea is to design an extended arm. The extended arm is directly connected to the gripper and also the gripper support to carry the load by the gripper.

3.1. Vehicle:

The initial plan is to choose the types of wheels for the vehicle. As it has been discussed to the background study there are different options to choose the wheel type for specific application. In this master's thesis we are focused on developing a vehicle which will work in an indoor environment. The best, simplest and effective option for the indoor environment would be the **Standard Wheels** as the surface of the University Lab is mostly flat and even. This type of wheel provides more stability and reliability while moving objects from one point to another within a controlled indoor space.

Then we have another good option to choose are the **Omni Wheels.** This type of wheels is great choice if the indoor environment is relatively confined and requires maneuvering around tight corners or obstacles. Their omnidirectional movement capability can optimize space utilization.

For this master's thesis we have chosen the **Mecanum Wheels** (Figure 30). The reason we have chosen this type of wheels as there is already available mecanum wheeled base in the Lab. These are the type of omnidirectional wheel designed to provide maneuverability and versatility to vehicles and robots. They consist of a central hub with multiple rollers mounted at an angle around its circumference. The key feature of mecanum wheels is their ability to move in any direction while maintaining a consistent orientation.

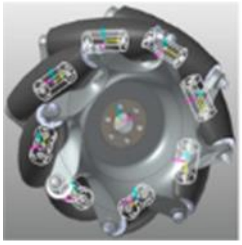

Figure 30 - Mecanum wheel [17]

Each roller on a mecanum wheel is set at a 45-degree angle to the wheel's rotation axis. When these wheels are installed on a vehicle in specific orientations, the combined motion of all the wheels allows the vehicle to move in multiple directions, including forward, backward, sideways, and diagonally. Figure 31 shows the mecanical base with motor and wheel assembled.

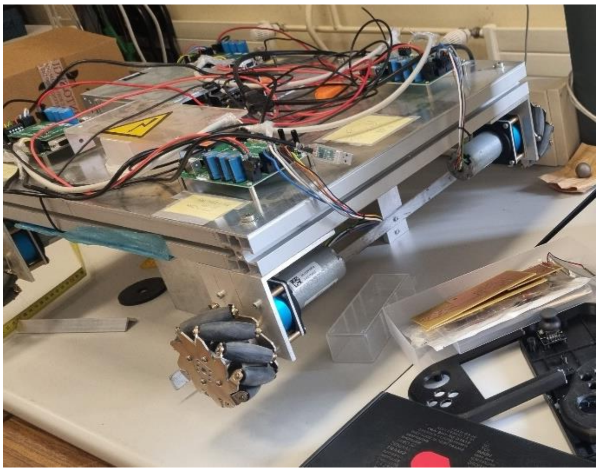

Figure 31 - Mecanical base with motor and wheel assembled

The mechanical base we have used for the master's thesis is already in the Lab. There are four aluminum profile which holds the rectangle base. The dimension of the base is 690mm x 500mm x 168mm (L*W*H). There are four 100mm mecanum wheels each on connected to a Dunkermotoren BG 42 KIx30. Also, there are four controllers (TMCM-1630) for the motor from TRINAMIC and an ac to dc power supply unit.

3.2. Linear Lifting System:

To reach at specific height of the electrical component shelves a linear lifting mechanism is necessary. For the specific problem have been mentioned the plan was to choose a very simple and cost-effective mechanism. There are several linear guide types has described at the background studies. From the studies considering balance between precision, functionality, and cost-effectiveness for a pick-and-place robot, **Linear Rail Guides** would be a suitable choice. This mechanism provides smooth, precise linear motion, good compromise between performance and cost. For the prototype of the master's thesis a telescopic linear guide system with a transmission of movement by belt has been used. The linear guide system has developed by the Group 2, Curso 2022-2023, Master en Ingenieria Mecatronica. Figure 32 shows the Linear Lifting System used for the master's thesis.

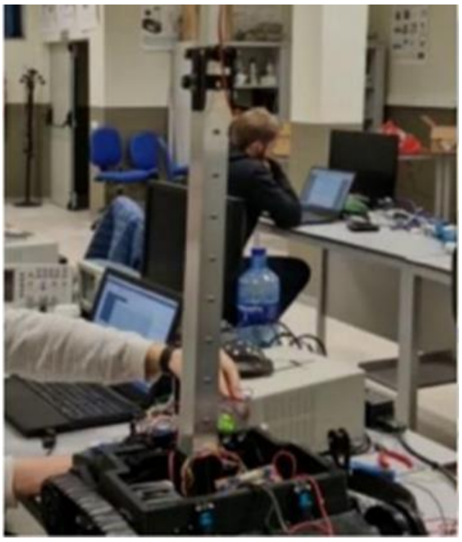

Figure 32 - Linear Lifting System used for the master's thesis

In this system, relative movement is achieved between a U-shaped aluminum profile that it will remain fixed to the pyramid embedded in it and with a pin that prevents its displacement vertically and a square mobile profile that slides over the first one and in which the actuator, which will rise by means of a linear guide system and which will establish the movement between both profiles.

3.3. Gripper Design:

The main goal of this thesis is to design a gripper to grab the electronic component drawer with the easiest and cost-effective method and that can be fabricated by the 3D printer from the university. As of the background studies the Parallel Jaw Gripper or Two-Fingered Gripper could be suitable, providing reliable and straightforward gripping for objects with uniform shapes.

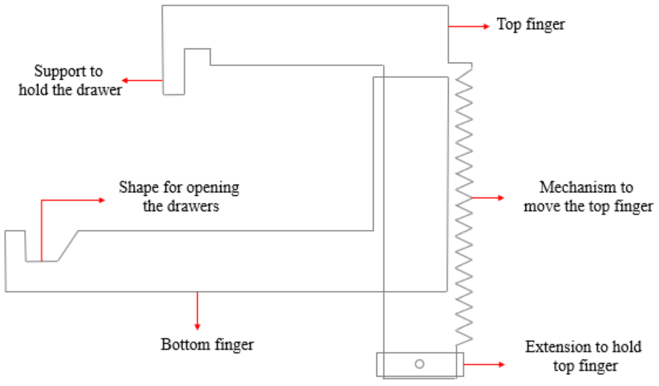

Figure 33 - Initial plan for the gripper design

The idea is to design a simplest gripper which fulfill the requirements for the problem. First of all, it is required to open the drawer from the shelves. For that we need a mechanism to open the box, so the plan is to make a mechanical shape that opens the drawer. In the figure 33, we can see at the bottom finger of the design there is a special shape to open the drawer. Then for grabbing the drawer after opening it the two-finger method has been used as it is relatively easier and cheaper, we discussed in the literature section. The movement of the top finger through the bottom finger will be established by rack and pinion method as it is easier and cheaper. At the bottom of the top finger there is an extra part added so that it doesn't come out from the bottom finger because of servo rotation.

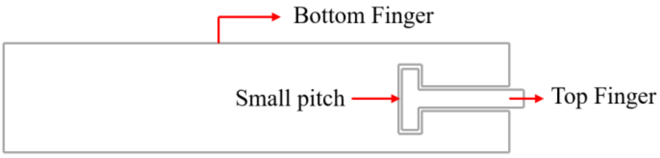

Figure 34 - Sliding mechanism of top finger and bottom finger

Figure 34, shows the idea for sliding the top finger to the bottom finger so that it can move easily and help to grab the drawer. There will be added small pitch between two parts so that it has a smooth moving. Some small fillets will be added also at the corners.

3.4. Control Design:

It is necessary to design an overall control of the rover for managing and regulating the various components of the system. The control system includes hardware, software and user interface to ensure efficient and user-friendly operation.

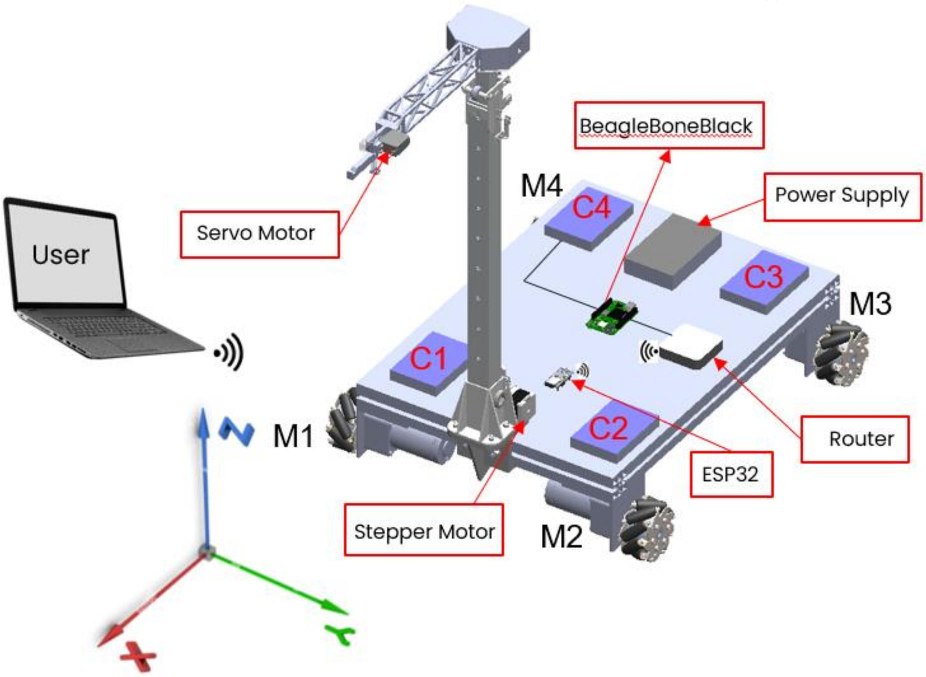

Figure 35 - Relation between components of the control system

Figure 35 shows the relation between different hardware and software components of the control system of the rover. There was four brushless DC motor to move the vehicle. M1, M2, M3 and M4 refers the motors of the rover. These four motors are connected to four motor controllers C1, C2, C3 and C4 respectively to control the speed or torque of the motor. These motors with controllers ensure the movement of the vehicle in the X (Forward and Backward) and Y (Left or right) direction. The four-motor controller is connected to BeagleBoneBlack (BBB) board by USB. This connection ensures serial communication between BBB and motor controller.

For moving the Gripper there is a servo motor. Because a servo motor can easily rotate to a specific angle. Then there is also a stepper motor to move the linear guide up and down. Both the servo and stepper motor are control by an ESP32. The reason is it’s easier, cheaper and reliable controller for these types of components. The Servo motor and Stepper motor both ensures the movement of the rover at the Z direction to grab object or adjust the height of shelves.

There is initial power supply of 24V and then using some circuit the required voltage will be provided to the corresponding components.

A user-friendly desktop-based GUI application have been developed. By this application user will be able to easily control the rover, movement of the griper and linear guide.

There is a router in the system and this router established the connection between different subsystem of the rover. The router is connected to BBB over ethernet cable. The ESP32 and user is connected to the same WiFi by the router. There is a server which runs on BBB. The communication between server and user and ESP32 is by means of TCP/IP protocol.

4. DETAILED DESIGN OF THE PROTOTYPE

This chapter will describe the design and development of the different parts for the rover. The 3d CAD model design of all parts will be discussed. Also, the electrical design and implementation of the control system, communication will be stated.

4.1. *Mechanical Design:*

All the mechanical design has been done for the prototype described in this section. Different parts of the gripper, Extended arm, Gripper support, Linear guide support and finally assemble of the all parts of the vehicle to evaluate the measurement. The design plans and mechanical simulation has been added to ANNEX I and II.

4.1.1. *GRIPPER DESIGN*

The gripper is divided into two parts. One is the top finger which will help to grab the electronic component drawers from the shelves. And the bottom finger which will carry the load of the drawer.

- **Top finger:** The top finger is 42mm long with 10mm width. There is a 70mm T-Shape geometry which goes inside the bottom finger to have the movement. At the front of the finger the length is 15mm that is 5mm larger than normal and there is a small cut of 2.5mm which helps the drawers to hold. At the T-Shape geometry, the rack and pinion mechanism has been added to have the linear movement from rotational force which helps the finger horizontally up and down to grab. Figure 36 shows the top finger of the gripper.

- **Calculation for rack and Pinion:**
  For single revolution in the pinion, As the height of the drawer is 35 mm,
  Approx. Movement required, Mr = 50 mm;
  Gear Module, M = 1.5 mm;
  Approx. Pitch Diameter, D = (Mr/PI) = (50/3.1416) = 15.92
  Number of teeth for the pinion, Z = (D/M) = (15.92/1.5) = 10.61 ≈ 10
  Pitch Diameter, d = (Z*M) = (10*1.5) = 15
  Mounting distance, a = 20mm
  Rack Pitch Height, H = a –(d/2) = 20-(15/2) = 12.5

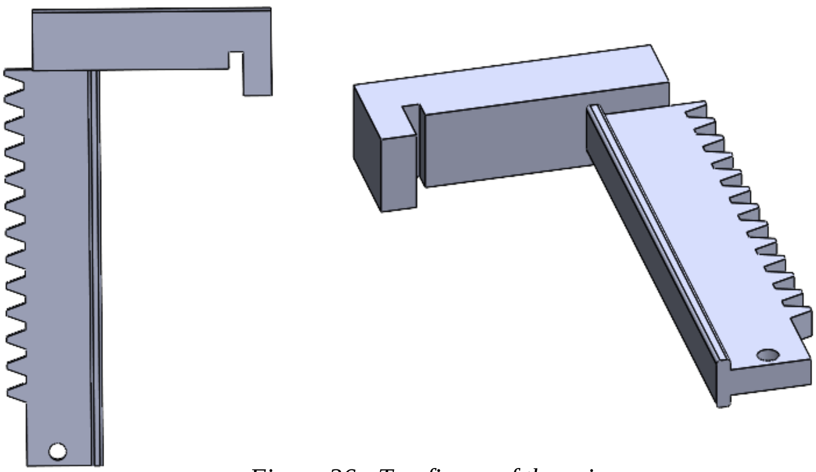

Figure 36 - Top finger of the gripper.

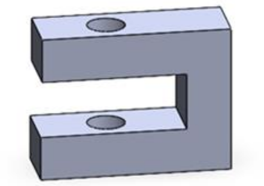

Figure 37 - Extension to hold the top finger inside bottom finger

At the bottom of the top finger there is 3mm hole to screw the extension. Figure 37, shows the simple extension that will support to keep the top finger, inside the bottom finger when there is uncertain movement will occur.

- **Pinion:** The circular gear which will be mounted to a servo motor and it will have contact with the rack in the top finger. This way it will convert the rotary motion to a linear displacement. As of the calculation before the pinion has ten teeth and the gear module is 1.5 mm. The width of the gripper is 3.5 mm and there is a 6mm cut with a 3mm hole at the back so that it fits to the servo. At the opposite site of the pinion there is 1mm depth slot to put a screw from this side to the other side and inside the servo. Fig 38 shows the pinion for moving the top finger.

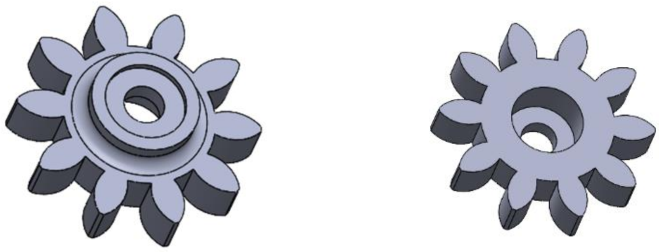

Figure 38 - Pinion for moving the top finger

- **Bottom finger:** The bottom finger has two different functionalities. In front of the bottom finger there is a mechanism to open the drawers from the shelves and there is a slot for sliding the top finger through that so that the top finger can easily move to up and down. There is also extension to put a servo motor to move the top finger and also support to add any extension to the gripper. The bottom finger is 80mm long, 15 mm high and 10 mm wide. At the front there is 2.25mm width teeth to open the drawers. At left side of the finger another 45mm extension added to screw up the servo and there is a hole of 10mm inside it to ensure the free movement of the servo and the screw put for holding the gear doesn’t touch the surface. Another extension has been added vertically to the finger at the end of the bottom finger to add some extension to reach the component shelves easily. The bottom finger of the gripper has been shown in Figure 39.

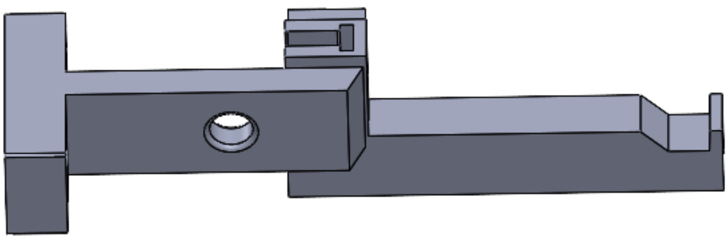

Figure 39 - Bottom finger for the gripper

- **Load to carry:** The maximum capacity of the electrical component drawer is 3kg. So, the maximum applied load for the bottom finger will be 3kg. The load has been converted to force (F = m*g);
  Where, F is force in Newtons (N)
  m is the mass in kilograms (kg)
  g is the acceleration due to the gravity
  We have,
  m = 3 kg
  g = 9.8 m/s2
  F = 3*9.8 N = 29.43 N

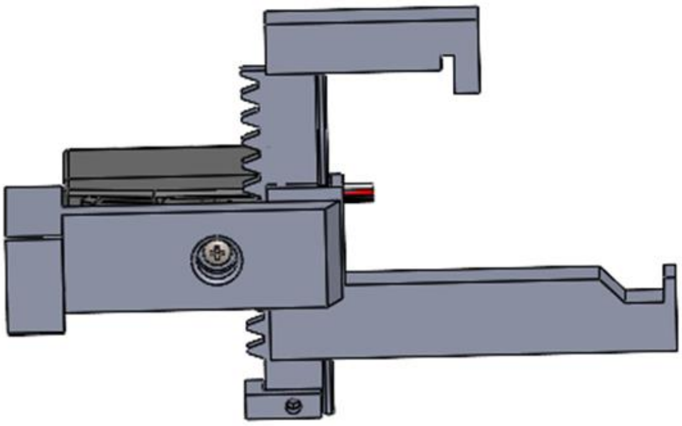

Figure 40 - Assembly of the gripper

Figure 40, shows the assembly of the gripper. The top finger, bottom finger, pinion, extension to hold the top finger and servo motor are assembled together to evaluate the performance.

4.1.2. *Extended Arm*

A mechanical simple arm has been designed to extend the gripper arm. For designing the arm Truss structure has been used because this type of geometry provides high strength-to-weight ratio, efficient load distribution, excellent stiffness and stability and easy analysis and design. The total length is 260 mm which ensures the gripper can reach the shelves easily. The vertical dimension is 38.80 mm. At the both end there are two rectangle shape to connect with the gripper and the linear guide. The design ensures the stability with minimum uses of material. Figure 41 shows the Extended Arm for the gripper

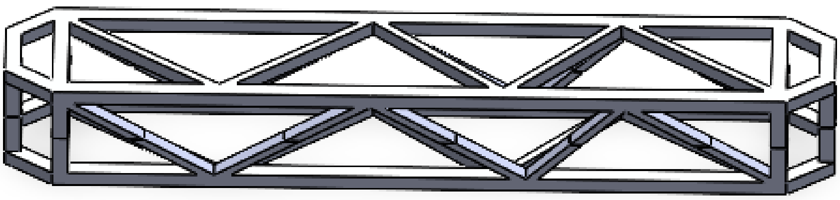

Figure 41 - Extended Arm for the gripper

4.1.3. *GRIPPER SUPPORT*

A box shaped designed have been carried out to connect the gripper and the linear guide. The bottom of the piece there is a rectangle shape which is designed to match the shape of the arm of the linear guide and also put a hole to screw it up. At the top of it a rectangle shape has been added with two holes so that the extension of the gripper can successfully join together. Some ribs have been added both at the bottom and top geometry to add some strength. There is specific cut so that wears from the bottom can easily enter to that section. Four rounds mountain geometry has been added to put the circuit on it. Figure 42 shows the gripper support.

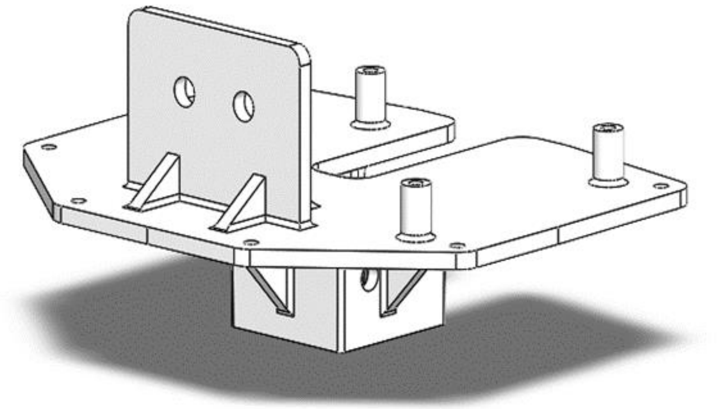

Figure 42 - Gripper Support

A cover for the gripper support has been designed. The cover adjusts the geometry of the gripper support. 6 mounting bosses has been added to screw it up. The is also a small rectangle cut to be able to control the power switch of the gripper.

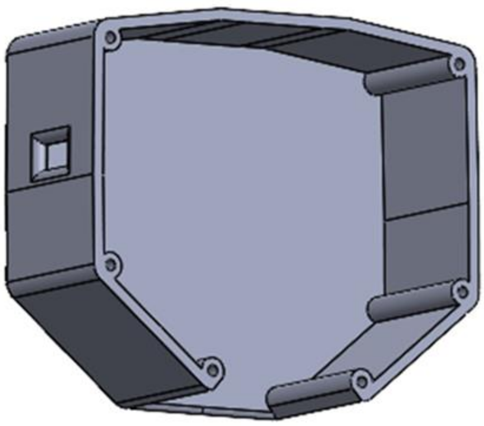

Figure 43 - Gripper Support Cover

Figure 43, shows the gripper support cover. It helps to protect the inside circuit for the gripper.

4.1.4. *LINEAR GUIDE SUPPORT*

A h-shape geometry has been designed to mountain the linear guide to top of it. The reason for designing the h-shape is to have better strength and stability. The slot has been made in a way that it holds the aluminum profile, and four bolt has been added. The top geometry matches the geometry of the bottom of the linear guide. Five holes have been added to screw the linear guide with it. At the middle of the front and at the bottom of the piece ribs has been added to have more strength.

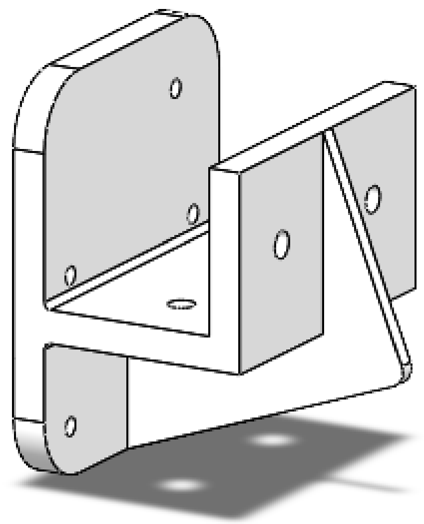

Figure 44 - Linear guide support

Figure 44, shows the linear guide support. This piece will be support to hold the linear guide and the gripper with the base of the rover.

4.1.5. VEHICLE ASSEMBLE

A mechanical base has been designed and developed to add all the parts together and to inspect all the parts are mating each other correctly. The gripper, extended arm, gripper support, linear guide, linear guide support and the main rover base has been correctly assembled together. No problems found at all to any of the parts for joining together.

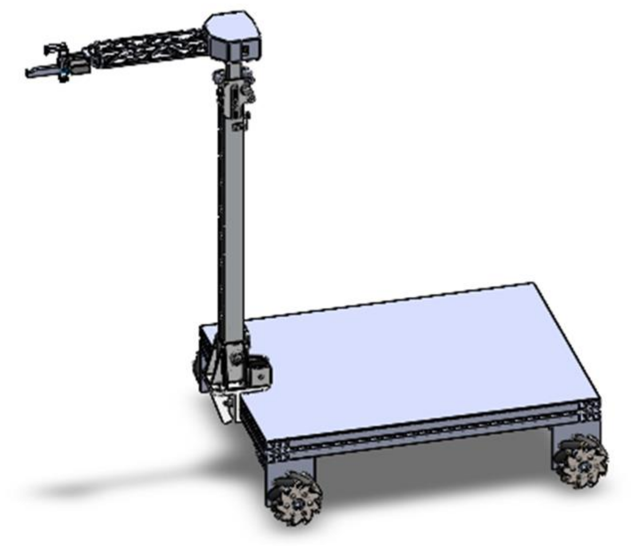

Figure 45 - Assembly of all mechanical parts of the rover

Figure 45 shows the assembly of all parts of the designed rover.

4.2. <u>Electrical Design:</u>

In this section the overall Electrical design have been discussed. The more detail design has been added to ANNEX III.

Throughout the electronic design, attempts were made to maintain certain main ideas that were focusing on its development. For the electrical design the base has been used it has four Dunkermotoren BG 42 KIx30 on it. Also, there are four TMCM-1630 motor controllers from Trinamic. The voltage required for driving the motor and power up the controller is 24V. In the base there were a 24V ac to dc power converter. But the initial plan is to replace the dc converter to 24V battery. It was decided to follow a modular design differentiating between different elements of the electronic system that could function relatively independently. Beside the base we need another two subsystems to be able to design and differentiate their functionality. The subsystems are the following:

- Subsystem for Linear Guide
- Subsystem for Gripper

The subsystems are established connection through printed circuit boards. Beside these subsystems we have also the BeagleBoneBlack and the router to have proper power. For this we didn't design any PCB. The router is connected to the base and from router there is an USB port which was the option to power up the BeagleBoneBlack from the router.

4.2.1. *<u>SUBSYSTEM FOR LINEAR GUIDE</u>*

The subsystem for linear guide is to connect all the electrical components together to establish the movement of the linear guide. The main components to power up and establishment of connection are ESP32, RS PRO Hybrid Stepper Motor, TMC2209 motor driver and a Dc-to-Dc converter. Figure 46 shows the ESP32. The specifications of those components are given below:

Figure 46 - ESP32 with the specifications [18]

The controller of the linear guide is the ESP32. The power supply needed for the ESP is 5V.

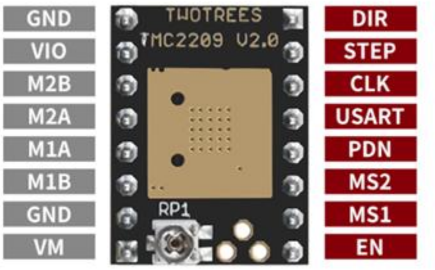

Figure 47 - TMC2208 Motor driver [19]

For controlling the stepper motor the TMC2208 driver (Figure 47) has been chosen because it is the easiest to use single-axis stepper motor drive. It provides smooth operation and noise free motor driving. It also ensures that there is no resonance and vibration.

MAXIMUM OUTPUT CURRENT: 1.4A
RECOMMENDED WORKING CURRENT: 1.2A MAX
DEFAULT FACTORY CURRENT: 0.7A
MICROSTEP: 256 MICROSTEP SUBDIVISION
CONFIGURATION: STEP/DIR OR UART
LOAD DRIVE ELECTRIC RANGE: 5~36V
IC LOGIC WORKING VOLTAGE: 3.3V/5V

Figure 48 - Specification of TMC2208 Motor driver [19]

From the figure 48, it is seen that we need two input voltage to the driver. As the main base is working 24V, the idea is put that much voltage to the driver. And for the logic voltage a dc converter has been added to provide 3.3 V for the logic.

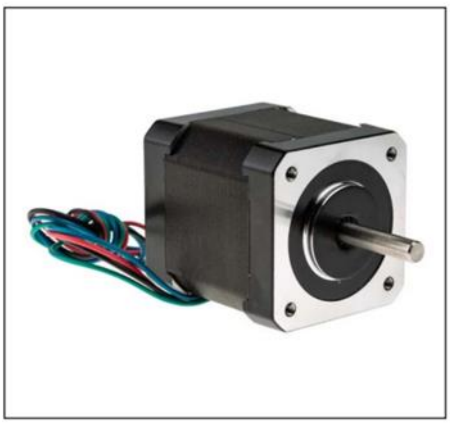

Figure 49 - Stepper motor for linear guide [20]

For moving the linear guide, the RS PRO Hybrid Stepper motor has been used. It ensures to make precise and controlled movements with electric devices. The motor divides a full motor rotation into several smaller, equal steps, for greater precision and higher efficiency at lower speeds. Figure 49 shows the stepper motor for linear guide.

Electrical Specifications

Voltage Rating	2.8 V
Current Per Phase	1.68 A
Number Of Wires	4
Resistance Per Phase	1.65 Ω
Wiring Arrangement	Bipolar
Resistance Accuracy	±10%
Inductance Per Phase	6.7mH
Inductance Accuracy	±20%
Rotor Inertia	68kg-cm²
Insulation Resistance	100 M Ω min., 500 Vdc
Dielectric Strength	500 Vac for one minute

Figure 50 - Specification of the stepper motor [20]

Figure 50 shows the specification of stepper motor. The power supply for the motor is provided by the motor driver. In the motor driver the current for the motor has been applied below 1.68 A.

Figure 51 - DC-DC converter [21]

Figure 51, shows the DC-DC converter to adjust the required the voltage. The TSR 1E is a 1 Ampere step-down switching regulator series and a drop-in replacement for inefficient 78xx linear regulators. The effective design allows full load operation up to +60°C ambient temperature without the need of any heat sink or forced cooling. The DC converter used for the subsystem is TSR 1-2433E which took 24V as input and convert it to 3.3V for the out. The specifications of the converter are the following:

Output Current Max: 1’000 mA
Input Voltage Range : 6-36 VDC
Output Voltage nom : 3.3VDC
Efficiency: 88%

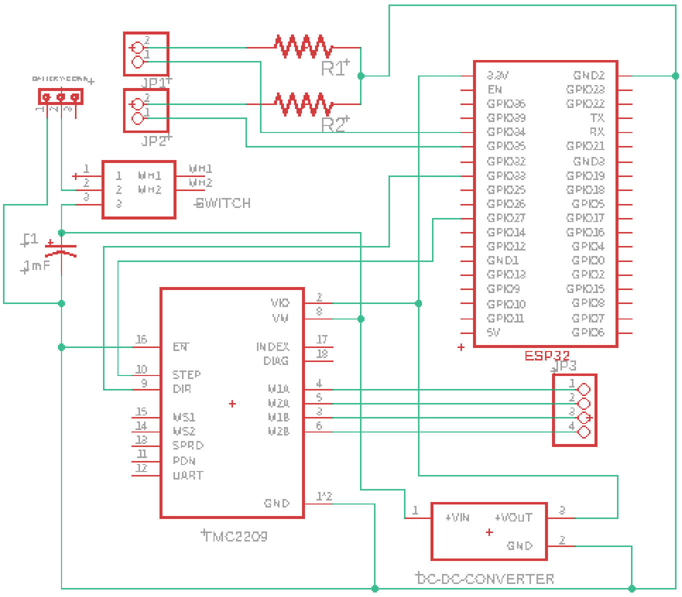

Figure 52 - Schematic diagram for subsystem for linear guide

Figure 52 shows the schematic diagram for the subsystem for linear guide. In the schematic the input (Connector) takes 24V to the circuit. A side switch has been added to the system. The VM pin at TMC driver is the input voltage. The STEP and DIR pin are the logic control pin connected to the esp32 which ensures the step to move and direction of motor moving respectively. The DC converter is connected to apply 3.3V to the ESP32. The M1A, M2A, M1B, M2B pins are connected to a connector to connect the stepper motor. There are two more two pin male connectors added to the schematic for the limit of the linear guide, upper and lower limit the guide can move.

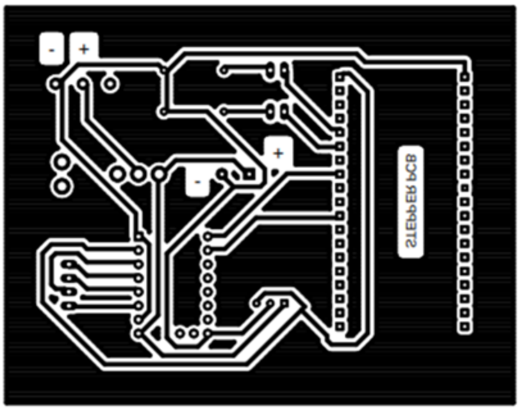

Figure 53 - PCB for subsystem for linear guide.

Figure 53 shows the PCB for the linear guide. The components from the previous schematic have been added and the components are placed in a way so that it takes very less space between components. The space between vias and pads and also the traces are added more than 32mil.

4.2.2. ***Subsystem for Gripper***

The subsystem gripper is to connect all the electrical components together to establish the movement of the gripper servo. The main components are the servo, ESP32 and DC converter. Parallax Standard Servo (#900-00005) has been used for the gripper. Figure 54 show the servo motor to move the gripper finger.

Figure 54 - Servo motor for moving the gripper finger [22]

The Parallax Standard Servo provides 180° range of motion and position control and also it can generate torque 38 oz-in at 6V DC. The servo supports 4 to 6V power supply and the maximum current draw is 140+/-50 at 6V (no load condition).

For the subsystem for gripper the TSR 1-2450E DC converter has been used. For the circuit it takes 24V as input and it provides 5V DC supply to the output. As for the specified servo 5 V is well enough to move the gripper finger. The specifications of the converter are the following:

Output Current Max: 1’000 mA
Input Voltage Range : 7-36 VDC
Output Voltage nom : 5VDC
Efficiency: 92%

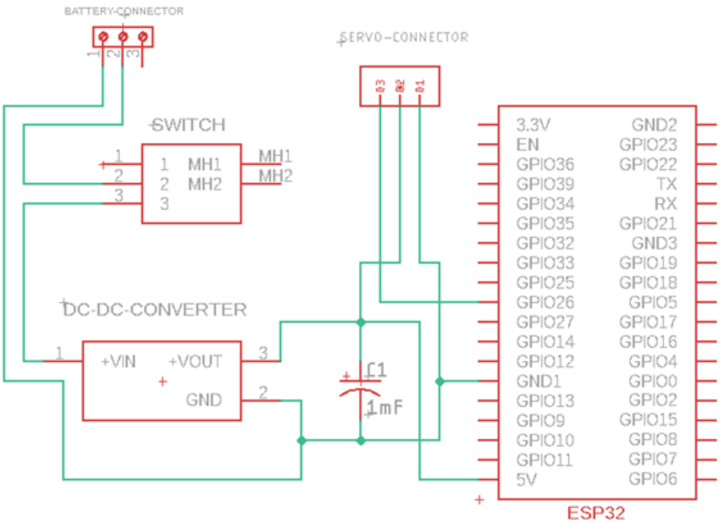

Figure 55 - Schematic diagram for gripper controller

Figure 55, shows the schematic for the subsystem for the gripper. A slide switch has been added to the system to maintain the power. The pins for servo are connected to the general purpose I/O pin of the ESP32. A 3-pin male connector has been added to connect the servo to the circuit.

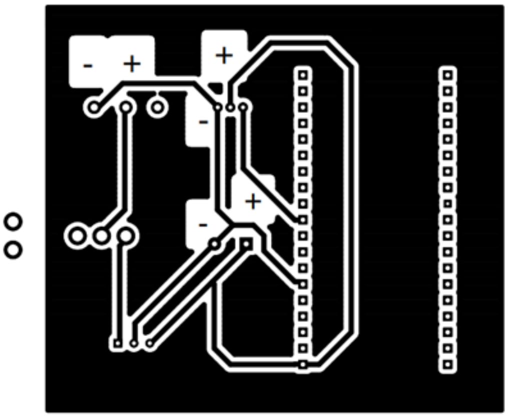

Figure 56 - PCB for gripper controller

Figure 56, shows the PCB for the gripper. The previous schematic's components have been added, and they are arranged so that very little space is required between them. There is more than 32 mil of space added between the traces, vias, and pads.

4.3. ***Detailed Software Design:***

This section will briefly describe the software design for the master's thesis. The whole software system of the rover is divided into three parts. The programming is done using C++ as it is robust and fast for embedded programming. The Qt platform is used to develop the software.

1. Rover Controller (main controller): The Beagle Bone Black is the main controller of the rover. Every different client or user communicates with it and send or receive the necessary data required for the rover. The main function of it is to receive data from the client to move the   move the linear guide up or down and open the gripper and close for grabbing.
2. Gripper and Linear Guide Controller: An ESP32 is the controller for the gripper and the linear guide. Normally the user sends necessary movement data to the rover controller and it forwards those command to ESP32. It receives those commands and execute the specific task.
3. Client or User Interface (Laptop): For controlling the rover a desktop based has been developed. By this app user can easily move the vehicle in different direction, can move the gripper up and down and also open the drawer, grab it and release it.

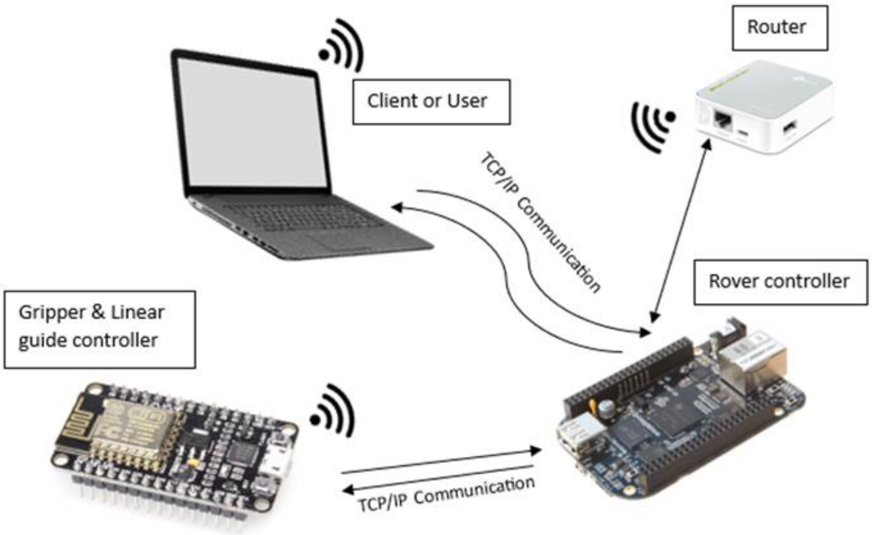

Figure 57 - Communication between different control unit

Figure 57 show the communication between different control units.

4.3.1. *COMMUNICATION PROTOCOLS*

The Beagle Bone Black, ESP32 and User interface has been connected through WiFi. The motors of the rover are connected to the Beagle Bone Black by USB serial port.

Communication between User and Beagle Bone Black: The communication between the user and Beagle Bone Black has been established by TCP/IP connections. The ‘**QTcpSocket’**class has been used to communicate between them. TCP (Transmission Control Protocol) is a reliable and connection-oriented protocol used for data transmission over networks. The TCP protocol has been used because of its higher reliability, capability of error detection and correction, ordered data delivery, good flow control, full duplex communication and moreover suitable for various applications.

Communication between Beagle Bone Black and ESP32: The **‘WiFiClient’** class has been used for communication between main controller and ESP32. It is part of the ESP32 Arduino core and typically used for establishing TCP/IP connection over WiFi networks. The ‘client.connect()’ function attempts to establish a connection to a specified server IP address and port number.

Communication between Main controller and Motor controller: The communication between Beagle Bone Black and the TMCM-2209 motor driver has been established by USB serial communication. The TMCM-2209 is a motor driver module from Trinamic that supports the **UART** (Universal Asynchronous Receiver-Transmitter) serial communication protocol for communication and configuration. UART is a standard protocol for serial communication between devices, and it is widely used for connecting microcontrollers, sensors, and other peripherals.

4.3.2. *USER INTERFACE*

The user interface has been developed for desktop users. The user interface has been three different windows to perform different specific task. The first window is the main window (Figure 58) which is used to establish the connection between the user and the server or the main controller.

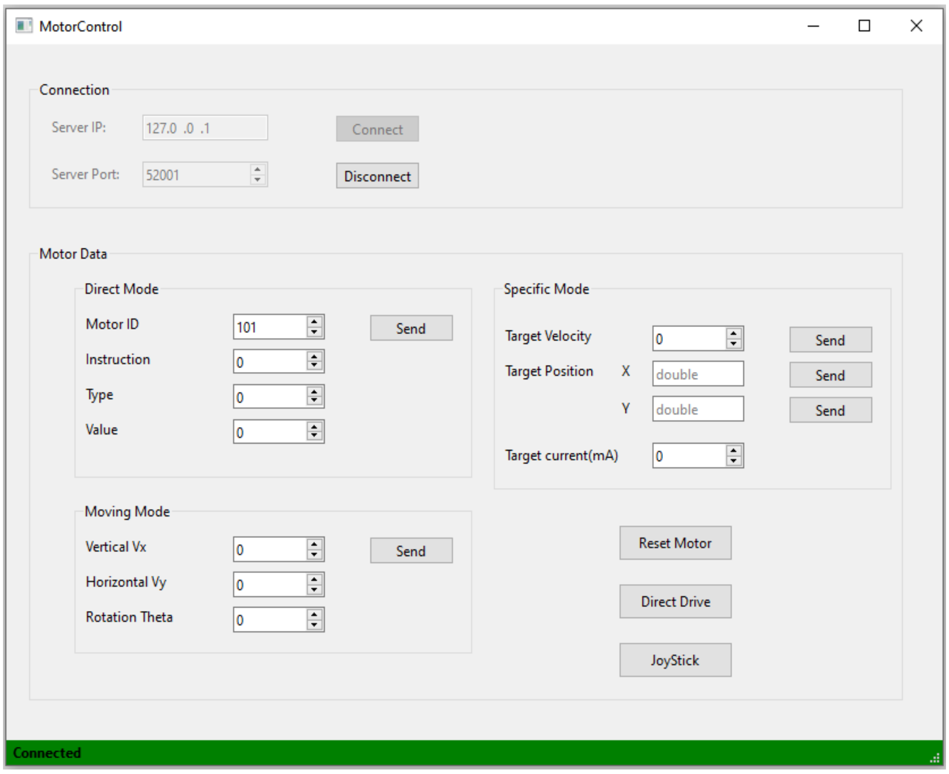

Figure 58 - Initial window to establish the connection

The main window allows to put a specific IP address and server port from the user to connect the desired server. Then There is Direct Mode which has been established to run the specific motor from the four. This sends Trinamic Motion Control Language (TMCL) commands to configure and control the motor. There is also Moving mode which helps you to set up velocity for the X and Y direction. In the Specific Mode it has been developed to move to specific position by knowing the position X, Y of that position where there would be a fixed start position. Then there are three more button one is to reset the motor to 0 so that in any case we have to stop the motor. The Direct Drive button will open a new window which is the main window to control the whole rover with gripper and linear guide.

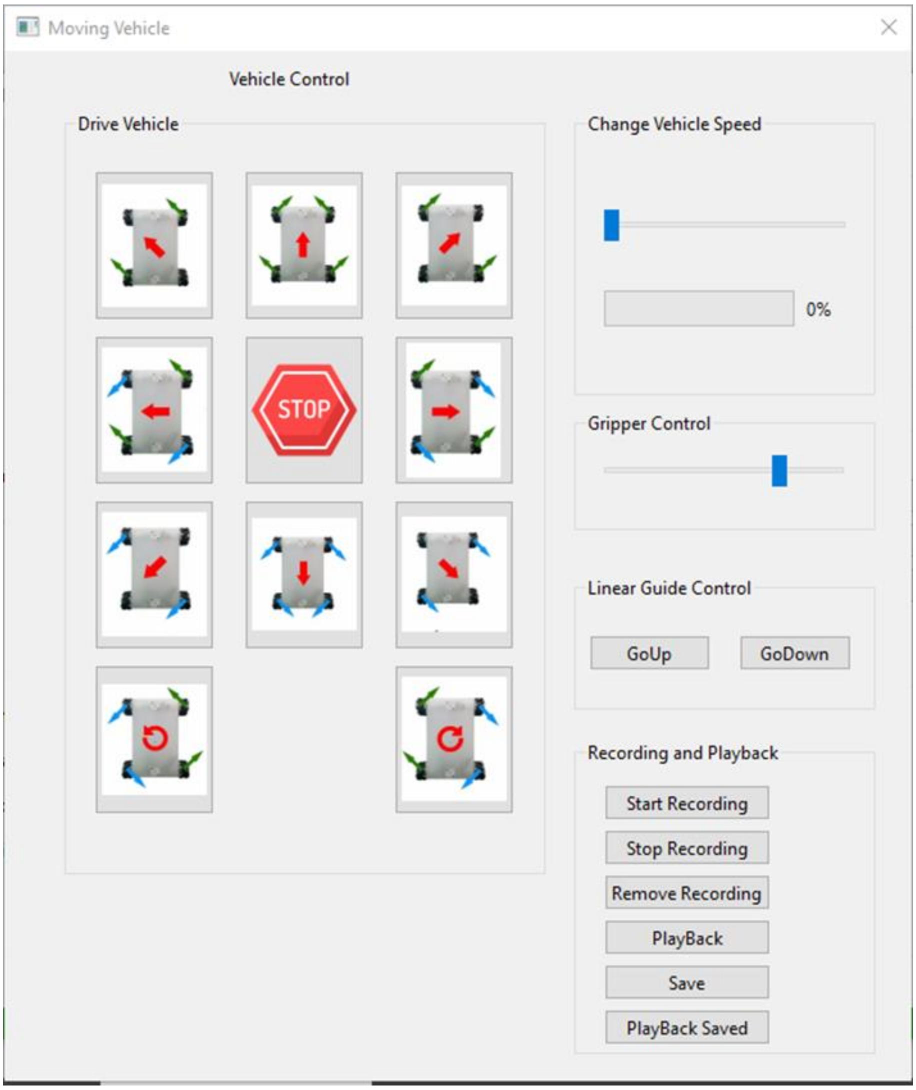

Figure 59 - Window to Move the vehicle

Figure 59 shows the vehicle driving window. This is the window which can move the vehicle to 10 different directions. There is also a slider to change the speed of the vehicle. Then another slider to open or close the gripper. It also has the linear guide control there are two buttons GoUP is to move the linear guide to up direction and the GoDown button is to move it to the down direction. Then we have the automation functionality Recording any movements and play it back when necessary or for specific task. The buttons are for specific functions like start recording, stop and delete the recording vector, play back and finally it allows us to save specific vector to a file and then playback that saved file anytime for later uses.

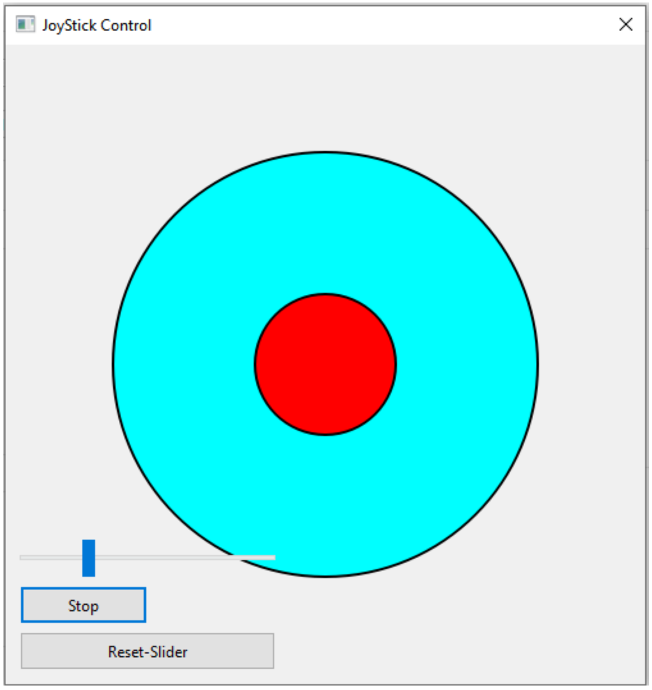

Figure 60 - Window to implement virtual joystick

Figure 60 shows the joystick window. This is the window to move the vehicle with the virtual joystick. The joystick moves and it has X and Y direction value. The idea was to take those X, Y co-ordinate and calculate the theta and map it for movement the vehicle to a specific direction smoothly.

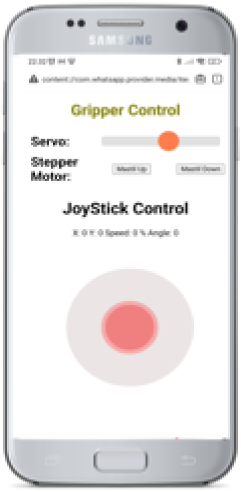

Figure 61 - Web Application to control the rover

Figure 61 shows the web application to control the rover. The server runs on ESP32 and by connecting with WiFi it is possible to access the web page from any device. The idea was to have a smooth driving of the vehicle as this user interface is device independent. The web application works successfully, it can control the gripper and servo of the rover. But the integration of the graphical joystick with the rover hasn't been established.

4.3.3. *VEHICLE MOVEMENT*

For moving a mecanum wheeled vehicle it is necessary to define a co-ordinate system to each wheel and also to the main base. This coordinate system helps to move the vehicle to specific direction quite easily.

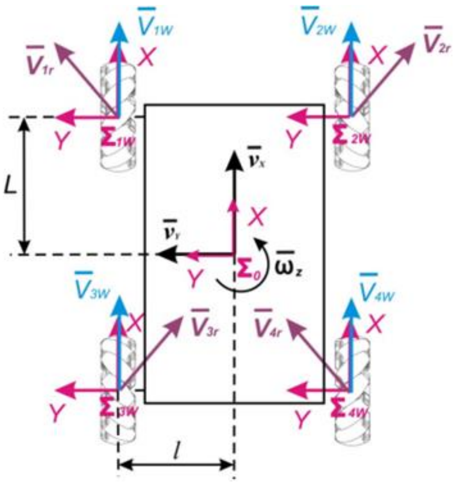

Figure 62 - Vehicle coordinate system [23]

Figure 62 shows the coordinate system for the mecanum wheeled vehicle. Here, Σ_0 and Σ_{iw} (i= 1,2,3,4) base coordinate system and wheel coordinate system correspondingly.

V_{iw} (i = 1, 2, 3, 4) - the velocity vector corresponding to wheel rotation,
V_{ir} (i = 1, 2, 3, 4) - the tangential velocity,
where $V_{iw} = \omega_{iw} R_w$, and R_W - is the radius of omni-directional wheel, ω_{iw} - is the angular velocity of the omni-directional wheel i.

The angular velocity of the wheels is described by the following matrix [23],

$$\begin{pmatrix} W_{1w}(t) \\ W_{2w}(t) \\ W_{3w}(t) \\ W_{4w}(t) \end{pmatrix} = \frac{1}{R_w} \cdot \begin{bmatrix} 1 & -1 & -(L+l) \\ 1 & 1 & (L+l) \\ 1 & -1 & -(L+l) \\ 1 & 1 & (L+l) \end{bmatrix} \cdot \begin{bmatrix} v_x(t) \\ v_y(t) \\ \omega(t) \end{bmatrix} \tag{4.1}$$

Where, L = the distance from each wheel shaft to the gravity centre of the vehicle on the X axis
l = the distance from each wheel shaft to the gravity centre of the vehicle on the Y axis
$v_x(t)$ and $v_y(t)$ are the speed component to the X and Y direction correspondently
$\omega(t)$ is the angular speed component

The equation provides the angular velocity for each wheel in rad/sec. We have used the TMCM-1630 from TRINAMIC and it works µsteps/sec. The formula for converting rad/sec to µsteps/sec is,
µsteps/sec = (rad/s ÷ 2π) *(steps/revolution*gear ratio)

By changing the value of $v_x(t)$, $v_y(t)$ and ω(t) to positive, negative and null the vehicle specific movement has been achieved.

5. RESULTS AND DISCUSSION

This chapter briefly describes the corresponding results or outcomes of the master's thesis. The challenges have been faced during the test process also discussed here.

The test has been done by the rover have been carried out different face and at specific face the focus was to achieve the objective of the master's thesis.

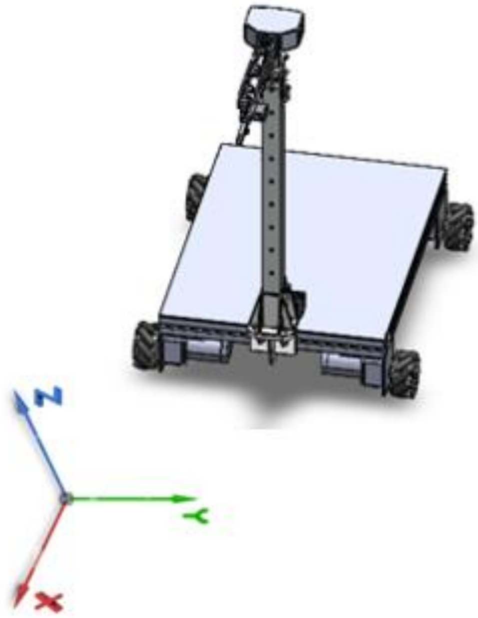

Figure 63 - Coordinate System for reaching the shelves

Figure 63 shows the coordinate system for reaching the shelves. The X is the depth direction which indicates the movement of the gripper for forward and backward, Y is the direction for movement of the gripper horizontal direction side to side and Z is the vertical direction which indicates the up or down movement of the gripper.

5.1. Opening the drawer from the Shelves

The first specific objective was to open the drawer from the electrical component shelves. A small mechanical cut added to the bottom finger of the gripper so that it adapts the geometry of the opening face of the drawer.

Figure 64 - Opening the drawer from shelves

From the figure 64, it is seen that the gripper can successfully open the drawer. The drawer opening operation have no issue at all but the observation for opening the drawer is that if the bottom finger reaches the middle position of the drawer, it is the best. But it also possible to open the drawer at the left or right end but would be not good for later picking operation.

5.2. Picking drawer from the Shelves

One of the main objectives of the prototype was to pick the drawers. For designing the gripper, the physics theory center of mass has been considered so that the mass distribution should be good and the drawer doesn't fall from the gripper or the gripper can grip it better.

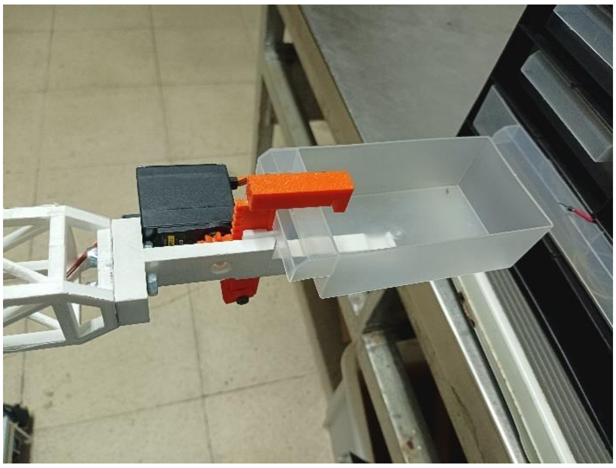

Figure 65 - Picking drawer from the shelves

From the figure 65, it is seen that the gripper can successfully grip the drawer. For grasping the drawer, it is important to take the gripper finger to the mid position of the width of the drawer. If the position is little bit left or right the gripper still successfully grips the it but if the position is nearer to left or right end it might make an undistributed mass and the drawer will fall. The required precision is +10 mm to Y direction. As it has been mentioned before there are three different dimensions of boxes, so the test has been done for the three specific dimension. From figure 5.2. we can see it is the smallest from the three and the gripper grasp it successfully without any problem.

Figure 66 - Picking drawer from the shelves (medium drawers)

Figure 66 shows the gripper can successfully grasp the 120 mm width drawers. As the width of the drawer increases it is very important to have the gripper position at very middle, otherwise the drawer can fall from the gripper.

Figure 67 - Picking drawer from the shelves (largest drawers)

From the figure 67, it is seen that the largest drawer which width is 260mm has been successfully picked up by the gripper. For the gripper the width of the drawer is a bit more but there are actually no problems picking when it comes to grab at the middle position. But from the detailed observation if the width of the gripper finger could be increase from 10mm to 20mm, it would be very good for this group of drawers.

Figure 68 - Picking drawer from the shelves with loads

Figure 68 shows the gripper grab the drawer with some weight. For designing the gripper, it has been considered that how much load or weight it should carry. The largest drawer has a capability of store 3kg of weight. So, for the design it has been considered to adapt the force will be generated to the gripper. A 500gm metal object has been put to the drawer and it successfully carry that load. Normally electrical component drawer doesn't carry 3kg of weight but still the gripper will be able to pick it but the gripper support of the linear guide will for this prototype.

5.3. Placing the drawer to a specific place

Placing the drawer to a specified place is important for any pick and place robot. Placing the object to right place ensures the effectiveness of the robot.

Figure 69 - Placing the drawer to specific place

Figure 69 shows the gripper can successfully place the drawer to a specific place. There are some observations for the placing operation. When the placing operation has been done the gripper already hold the half of the box and the gripper grab the drawer horizontally. So, mass distribution is kind of crucial here. So, the half of the box should be at the placing surface. And after placing that the gripper should be release the drawer, came backward position a bit and then push the drawer towards the placing surface by the bottom finger.

5.4. Pick from specific place to back it to the shelves

After successfully picking and placing it is required to sometimes take that drawer back to the shelves where it was. For achieving this specific objective several tests have been done. The observations have been described below.

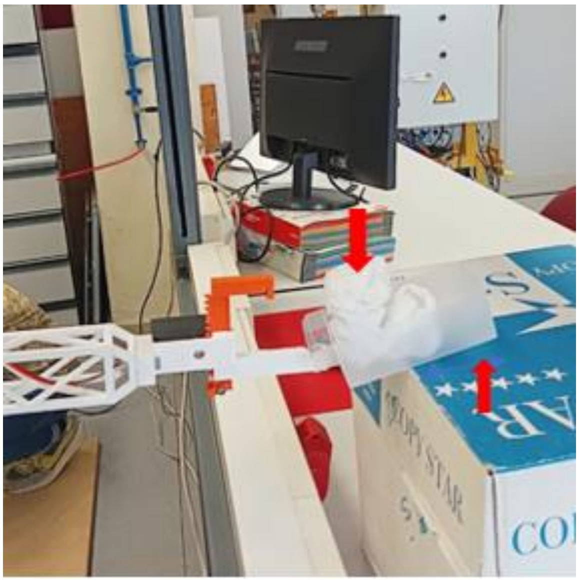

Figure 70 - Unsuccessful operation of picking

Figure 71 - Successful operation of picking

Figure 70 and 71 shows the pick operation from any specific place (not from the shelves). Figure 70 shows the unsuccessful operation of picking and 71 shows the successful method of picking the drawer from specific place. From figure 70, it is clearly visible that when the gripper was trying to take it front the drawer is falling and this is a challenge for placing the drawer back on the shelves. It is seen that there are some masses added inside the drawer, and the mass produces an unbalanced distribution of mass to the drawer and at the front, there is more mass, so it falls. On the other hand, from Figure 71, it is clearly visible there is some mass at the back end, and this time, it doesn't fall and successfully picks that item. So, for picking from any specific place by the gripper, it is essential to have the equilibrium of mass distribution inside the box. A possible solution for this particular problem could be adding another degree of freedom to the gripper so that it can rotate and grab the box horizontally.

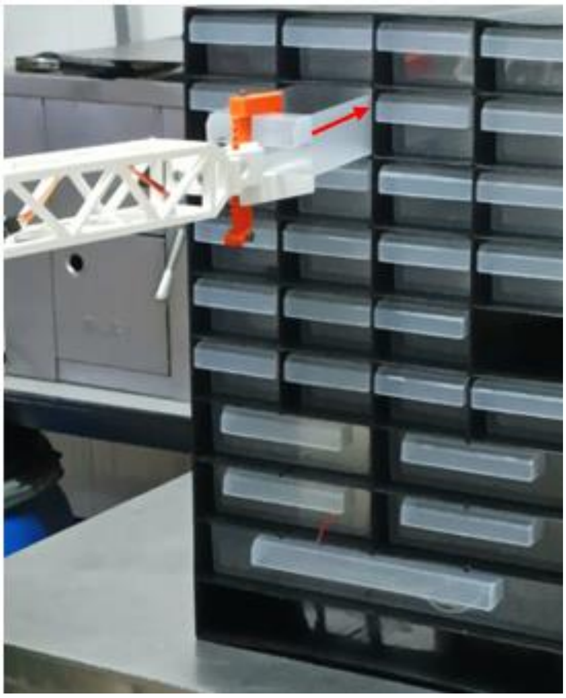

Figure 72 - Placing back the drawers to the shelves

Figure 72 shows the operation of placing the drawer back, and it is seen that the placing has been successfully done. But there are some important observations that the position of the gripper with the vehicle and linear guide should be very precise. The required precision for placing back to the shelves is + 4mm both the X and Z direction.

5.5. Moving the linear guide

The linear movement of the linear guide is established by generating a pulse by the programming to the stepper motor. Changes of direction demonstrate the upper movement or lower movement.

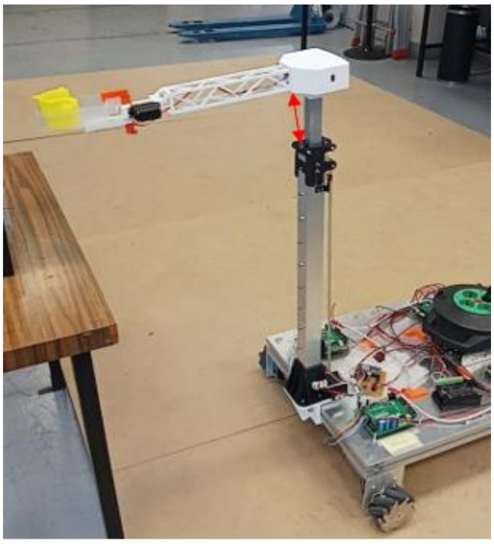

Figure 73 - Linear guide movement (initial position)

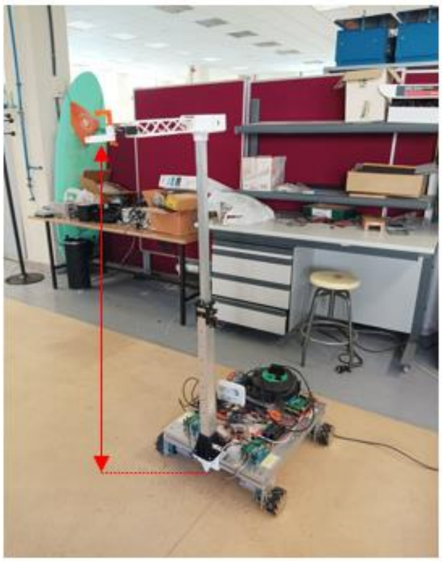

Figure 74 - Linear guide movement (top position)

Figures 73 and 74 show the changes in the height of the gripping system. The minimum height is 93.5 cm and maximum height it can reach is 142cm from the surface. The linear guide works perfectly to adjust the height of the specific shelves to pick the drawers. There are two limit switches have been added to the system to stop the movement at the top or bottom end.

5.6. Moving the Vehicle

Moving the vehicle with precise positioning is very important for pick and place the robot. For precise location, the speed of each wheel also matters. A mecanum-wheeled rover has ten different movement operations.

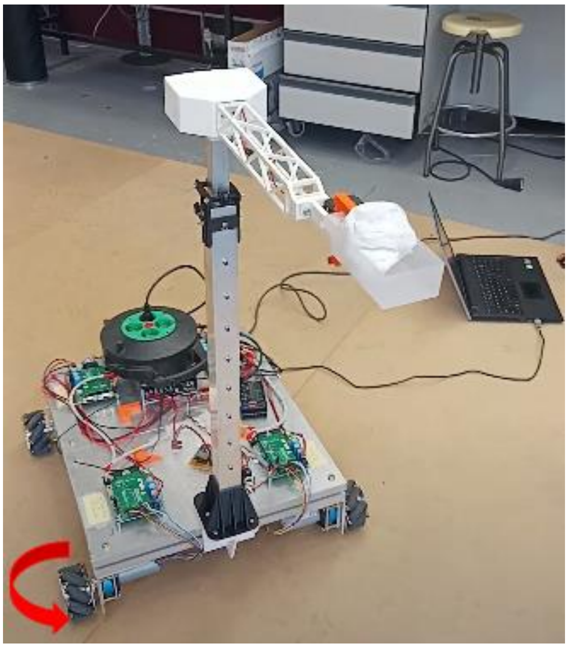

Figure 75 - Rotational movement of the vehicle

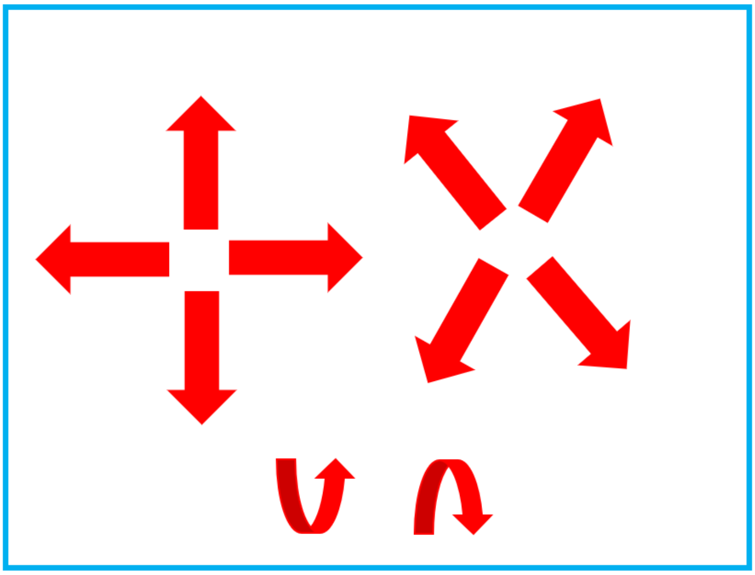

Figure 76 - Different direction of movement of the vehicle

Figure 75 shows the rotational movement of the vehicle, and Figure 76 shows all the different movement the vehicle has. The vehicle has successful movement in every direction, like forward, backward, right, left, forward diagonal, backward diagonal, and also left and right turn. Even though the vehicle has been moving perfectly, there are some problems with those movements.

5.6.1. *Observations for the movement of the vehicle:*

There are some specific observations for the movement of the vehicle those are:

- The movement of the vehicle through the X-axis is perfect, and it moves the vehicle forward and backward perfectly. The change in speed doesn't affect the positioning of the vehicle for forward and backward movement.
- The movement of the vehicle through the Y-axis is not perfect. For example, going to the right or going to the left, the movement is not parallel, and it makes a positioning error. When the speed increases, it has a kind of better performance.
- The problem could be the wheel alignment and calibration are mismatched a bit.
- It could also be the uneven wheel wear, which leads to differences in rolling resistance, affecting movement in specific movements.
- It could also be uneven power delivery or mechanical issues with the wheel motor.
- It could be the algorithm or programming logic used for the lateral movement is not up to the mark.
- Another important matter is the wheel slip, which is already observed during the test.
- It can also be mechanical friction or inadequate clearance in the transmission can impede lateral movement.
- It is also observed that uneven or rough surfaces affect vehicle movement.

A probable solution for better movement could be the following:

- Rechecking that the wheels are correctly aligned and are symmetrically placed. Calibration the wheels again according to the manufacturer's instructions.
- Inspecting the wheels for wear or tear regularly. It may be rotated or replaced the wheel as needed.
- Test the wheel motor individually also, checking for mechanical obstructions, damaged gearbox, or issues with power distribution.
- Reviewing the left and right movement programs and inspection of motor commands are correctly calculated

- By adjusting the weight distribution and appropriate wheel materials, it is possible to optimize the vehicle traction on the surface.
- Adding suspension or adaptive control and implementing feedback control that takes into account surface variations.
- Speeding up for the vehicle when it comes to vertical movement.

5.7. *Automation of the pick and place operation*

The main challenge is to achieve the automation of the pick and place operation. For automation of tasks, the minimum requirements are to add different sensors, take feedback from the environment, and finally adjust the operation that needs to be done. As a lack of sensor elements, the idea was to implement automation in two different methods. One is recording the step that has been done for a specific pick and place operation and repeating the step by playing it back. Another idea was to start an initial position and then set up a target position and reach that position by updating the position every time. The detailed observations are below:

5.7.1. *Record step and playback*

Record and playback are very common methods to achieve some automation. The idea was first to set up an initial starting point for the vehicle and set the coordinate point as X, Y = (0,0). Then, there is a start button for recording; when it is clicked, the steps by the vehicle, linear guide, or gripper movement are saved with the timing of the operation done by the user interface. There is also a stop button to stop the steps. After stopping the recording, it is possible to playback the recorded actions. There are two more buttons added to save specific commands and play only specific saved steps for a repeat.

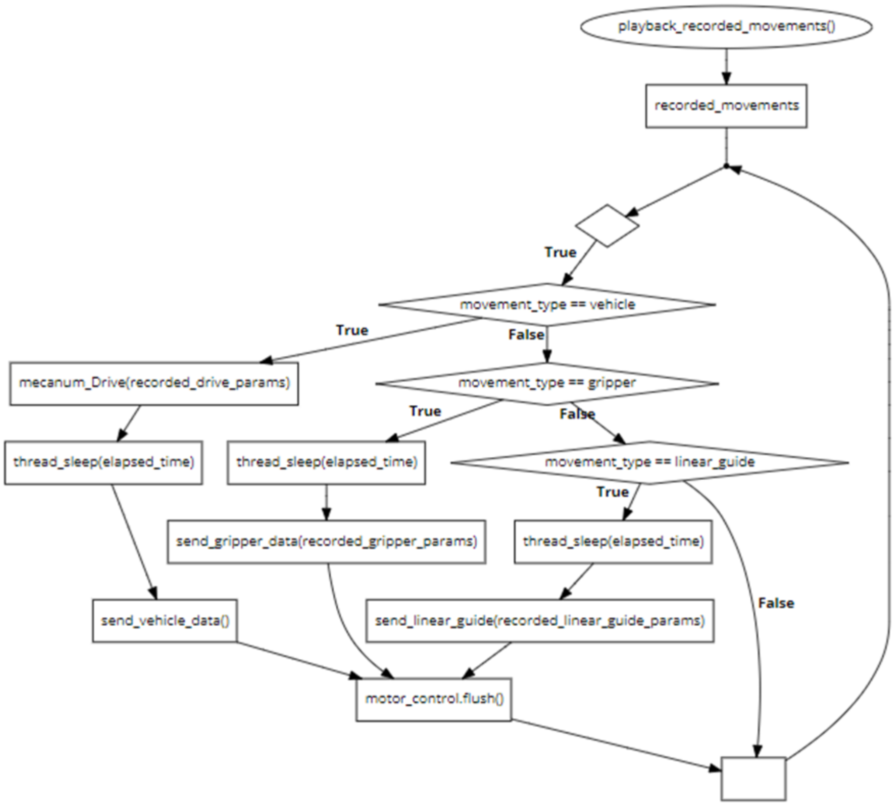

Figure 77 - Algorithm for play recorded step

Figure 77 shows the Algorithm for playback of the recorded movements. Paying back the recorded activity ensures the exact movement by calculating the elapsed time between one and another operation.

Figure 78 - Position of the gripper at the time of recording

Figure 78 shows the position of the gripper at the time of recording specific steps. It is clearly visible that the gripper is 55mm left from the middle of the shelves in Y direction. And for the X direction it touches the shelves.

Figure 79 - Position of the gripper at the time of playback (Y direction)

When the successful recording has been done, the record has been played back. Figure 79 shows the playback of the previously saved steps with the exact elapsed time between operation. It is seen that the position of the gripper is now $\pm$ 14mm to the Y direction. So, the positioning error is $\pm$ 30mm in the Y direction.

Figure 80 - Position of the gripper at the time of playback (X direction)

Figure 80 shows the playback of the previously saved steps with the exact elapsed time between operations. But in the picture, it is clearly seen that the vehicle is in a bit more forward position to the X direction. The displacement error is + 14mm to the X direction.

5.7.2. OBSERVATION FOR THE RECORD STEP AND PLAYBACK

The problems for not successfully following the steps could be the following,

- Erroneous starting position and angle of the vehicle at the start of the playback.
- It could be the timing and synchronization are not aligned properly.
- The server response or delay for any unwanted bug in the programming.
- Variations in the environment, such as surface conditions, friction, and obstacles, can impact the accuracy

The possible solution for the problem could be the following:

- Try to take a more precise position by adding some landmarks and also make sure the vehicle angle is the same at the time of repeating.
- Adding some sensor feedback and feedback control can be a great idea to solve the problem.

5.7.3. MOVE TO TARGET POSITION

Another method has been tried to test to go to a specific position by starting an initial fixed position (0,0) and setting up a small error margin so that the vehicle determines when it reached the target position. Before going to a loop, it calculates the distance and theta from the initial and target positions. When it enters the loop, it updates the current position till the error margin, and after finishing the loop, it stops the vehicle movement. Figure 81 show the algorithm to move to specific position.

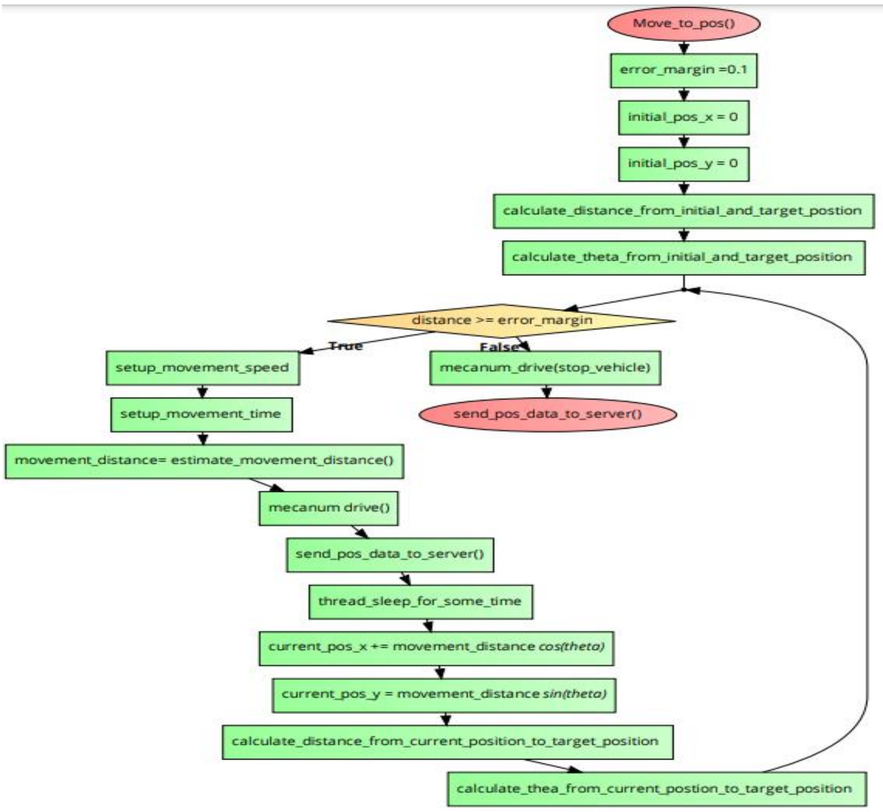

Figure 81 - Function to move the vehicle to a specific position in the 2D coordinate system

Finally, in the test, the vehicle doesn’t reach the specified position as there is no sensor and feedback system in the positioning system.

6. CONCLUSION & FUTURE WORK

Finally, this thesis effectively demonstrates the design, implementation, and assessment of an autonomous pick-and-place robot system for electrical components shelves. The system's integration of mechanical components, sensing technologies, and control algorithms enables it to pick and put items with accuracy and precision. The extensive experimental testing highlighted the system's strengths and identified areas for development. Notably, careful consideration of gripper design, load-bearing capacity, and mass distribution all had a substantial impact on the system's ability to grab and transport electrical components drawer effectively. The use of a mecanum wheeled rover permitted complex movements; however, problems with wheel alignment and lateral movement precision were identified.

The proposed automation approaches, which involve recorded step-playback and moving to target positions, show promise for efficient and repeatable procedures. However, environmental variances and synchronization issues must be handled for successful automation. The combination of sensor feedback and advanced control mechanisms has the potential to improve these automation systems.

This thesis adds new insights into the field of autonomous robotics for material handling by thoroughly analyzing the robot's mechanical, electronic, and software components. Future work should focus on overcoming the stated issues, perfecting automation techniques, and improving the system's flexibility to various manufacturing circumstances. Overall, this study improves the capabilities of pick-and-place robotic systems, contributing to the evolution of automation in industrial settings.

References

1. Li, M., A. Milojević, and H. Handroos, *Robotics in manufacturing—The past and the present.* Technical, Economic and Societal Effects of Manufacturing 4.0: Automation, Adaption and Manufacturing in Finland and Beyond, 2020: p. 85-95.
2. Huang, P.C. and A.K. Mok. *A Case Study of Cyber-Physical System Design: Autonomous Pick-and-Place Robot*. in *2018 IEEE 24th International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA)*. 2018.
3. Market.us. *Pick and Place Robot Market to Reach USD 7.4 Billion by 2032, Says Market.us Research Study | Analysis on Impact of US crises*. 2023 15 June 2023]; Available from: https://www.linkedin.com/pulse/pick-place-robot-market-reach-usd-74-billion-2032-says-belva-ann.
4. Kimura, N., et al. *Mobile dual-arm robot for automated order picking system in warehouse containing various kinds of products*. in *2015 IEEE/SICE International Symposium on System Integration (SII)*. 2015.
5. Liang, C., et al. *Automated robot picking system for e-commerce fulfillment warehouse application*. in *The 14th IFToMM World Congress*. 2015.
6. van Henten, E.J., et al., *An Autonomous Robot for Harvesting Cucumbers in Greenhouses.* Autonomous Robots, 2002. **13**(3): p. 241-258.
7. Zhang, H., et al. *DoraPicker: An autonomous picking system for general objects*. in *2016 IEEE International Conference on Automation Science and Engineering (CASE)*. 2016. IEEE.
8. Zhu, H., et al. *Strategy-based robotic item picking from shelves*. in *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2016.
9. Demaitre, E. *Robot Fleets Grow Demand for Warehouse Management Software, Interoperability Layer*. 2021; Available from: https://www.robotics247.com/article/robot_fleets_grow_demands_warehouse_management_software_interoperability_layer.
10. Azadeh, K., R. De Koster, and D. Roy, *Robotized and automated warehouse systems: Review and recent developments.* Transportation Science, 2019. **53**(4): p. 917-945.
11. Custodio, L. and R. Machado, *Flexible automated warehouse: a literature review and an innovative framework.* The International Journal of Advanced Manufacturing Technology, 2020. **106**(1): p. 533-558.
12. Hernandez, J., et al., *Current designs of robotic arm grippers: a comprehensive systematic review.* Robotics, 2023. **12**(1): p. 5.
13. Tai, K., et al. *State of the Art Robotic Grippers and Applications*. Robotics, 2016. **5**, DOI: 10.3390/robotics5020011.
14. Kemp, C.C., A. Edsinger, and E. Torres-Jara, *Challenges for robot manipulation in human environments [Grand Challenges of Robotics].* IEEE Robotics & Automation Magazine, 2007. **14**(1): p. 20-29.
15. Tsarouchi, P., S. Makris, and G. Chryssolouris, *Human–robot interaction review and challenges on task planning and programming.* International Journal of Computer Integrated Manufacturing, 2016. **29**(8): p. 916-931.
16. Components, R. *RS PRO 30 Drawer Unit*. Available from: https://docs.rs-online.com/2cce/A700000007670484.pdf.
17. Li, Y., et al., *Kinematic Modeling of a Combined System of Multiple Mecanum-Wheeled Robots with Velocity Compensation.* Sensors, 2020. **20**(1): p. 75.
18. watson, D. *ESP32 Pinout, Datasheet, Features & Applications*. 2020; Available from: https://www.theengineeringprojects.com/2020/12/esp32-pinout-datasheet-features-applications.html.
19. es.aliexpress.com. *TMC2208 Motor driver* Available from: https://es.aliexpress.com/.

20. componennts, R. *RS PRO Hybrid Stepper*. Available from: https://docs.rs-online.com/d4ce/A700000008880635.pdf.
21. mouser.es. *Traco power dc/dc converter*.
22. Mouser.es. *Parallax Standard Servo*. Available from: https://www.mouser.es/datasheet/2/321/900-00005-Standard-Servo-Product-Documentation-v2.-462659.pdf.
23. Tătar, M.O., et al. *Design and development of an autonomous omni-directional mobile robot with Mecanum wheels*. in *2014 IEEE International Conference on Automation, Quality and Testing, Robotics*. 2014. IEEE.

ANNEXES

The annexes are included in this document after the master's thesis report. These annexes contain more details and project-related materials. Plans, simulations, and any other essential information deemed necessary to comprehend the project can be found here. They are an excellent resource for deepening comprehension of the project and offering specific, supplementary information that can be very useful.

ANNEX I – PLANS

ANNEX II – MECHANICAL SIMULATION

ANNEX II – ELECTRICAL DESIGN

MASTER IN MECHATRONIC ENGINEERING

Autonomous pick & place robot for electronic component drawers in their shelves

TRABAJO FIN DE MÁSTER

ANNEX I – PLANS

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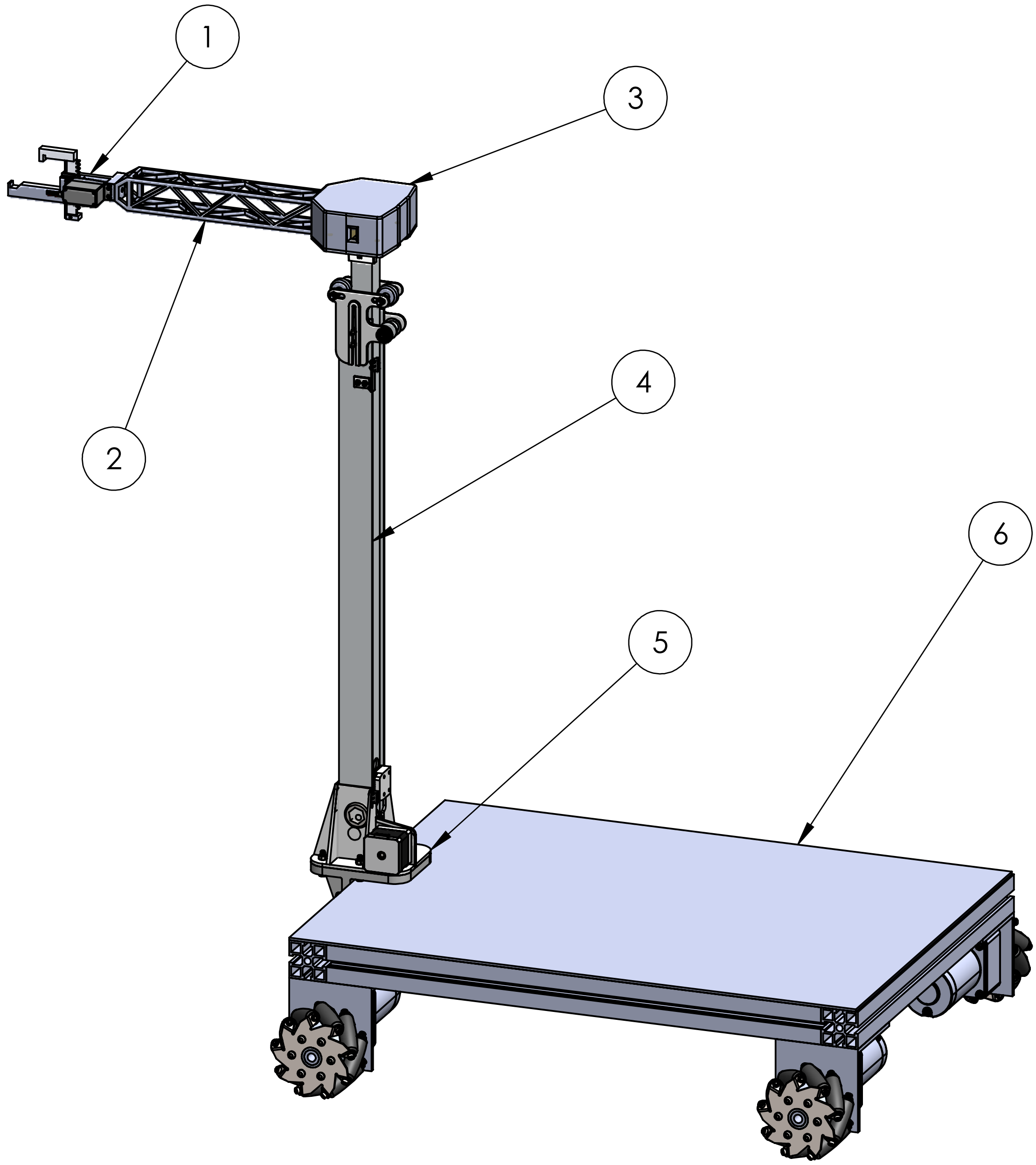

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Gripper		1
2	Extended arm		1
3	Gripper support		1
4	Linear guide		1
5	Linear guide support		1
6	Base		1

	NAME	DATE
DRAWN	Md. Shafiqul Islam	30/04/2023
CHK'D	Md. Shafiqul Islam	12/05/2023
APPV'D	Md. Shafiqul Islam	16/05/2023
Q.A	1	

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Name of the parts
Pick and Place Rover

DWG NO.
ROV-01-01-01

A4

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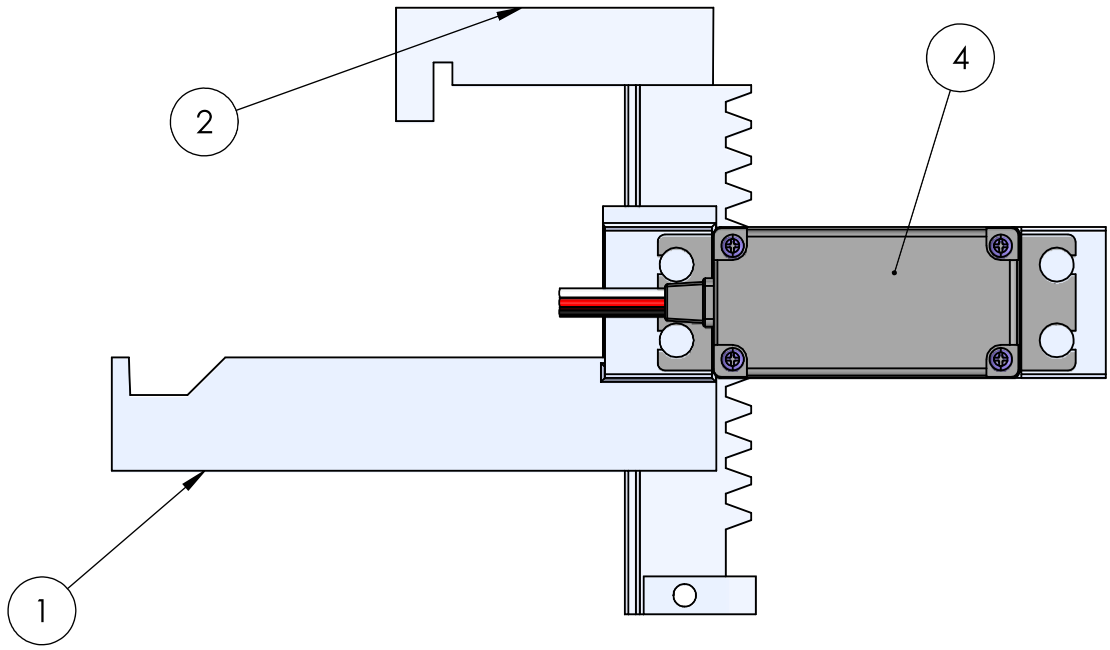

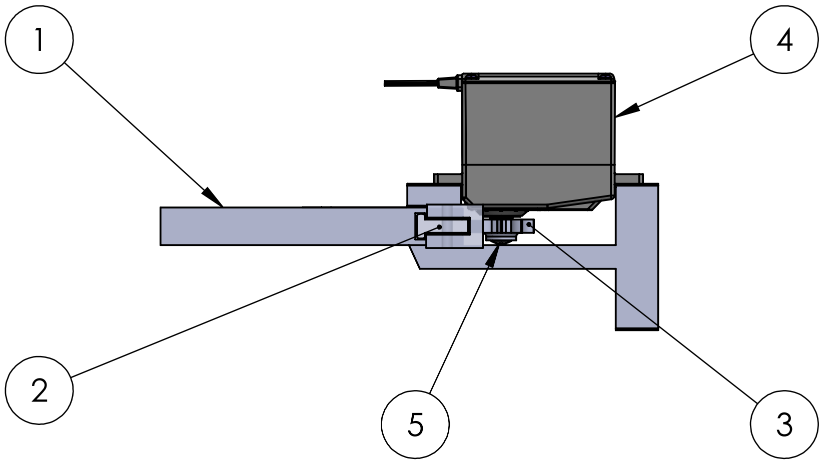

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1	Bottom_finger		1
2	Top_finger		1
3	Pinion_for_grip		1
4	servo_single		1
5	ISO 7045 - M3 x 6 - Z - 6N		1

	NAME	DATE
DRAWN	Md. Shafiqul Islam	22/04/2023
CHK'D	Md. Shafiqul Islam	28/05/2023
APPV'D	Md. Shafiqul Islam	30/05/2023
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Name of the parts

Gripper

DWG NO.

ROV-01-01-02

A4

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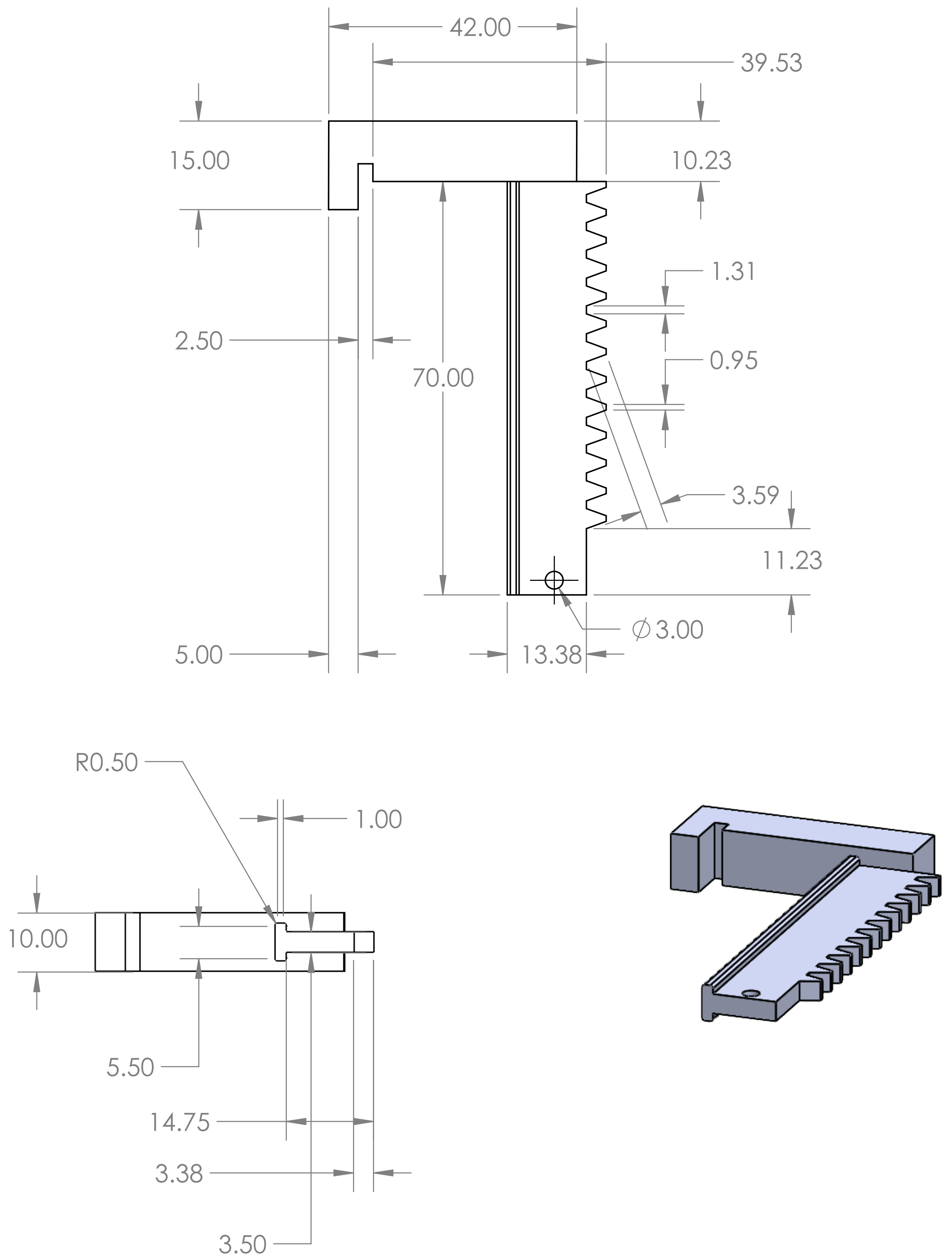

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APPV'D	Md. Shafiqul Islam	12/04/2023		
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Name of the parts

Top finger

DWG NO.

ROV-01-01-03

A4

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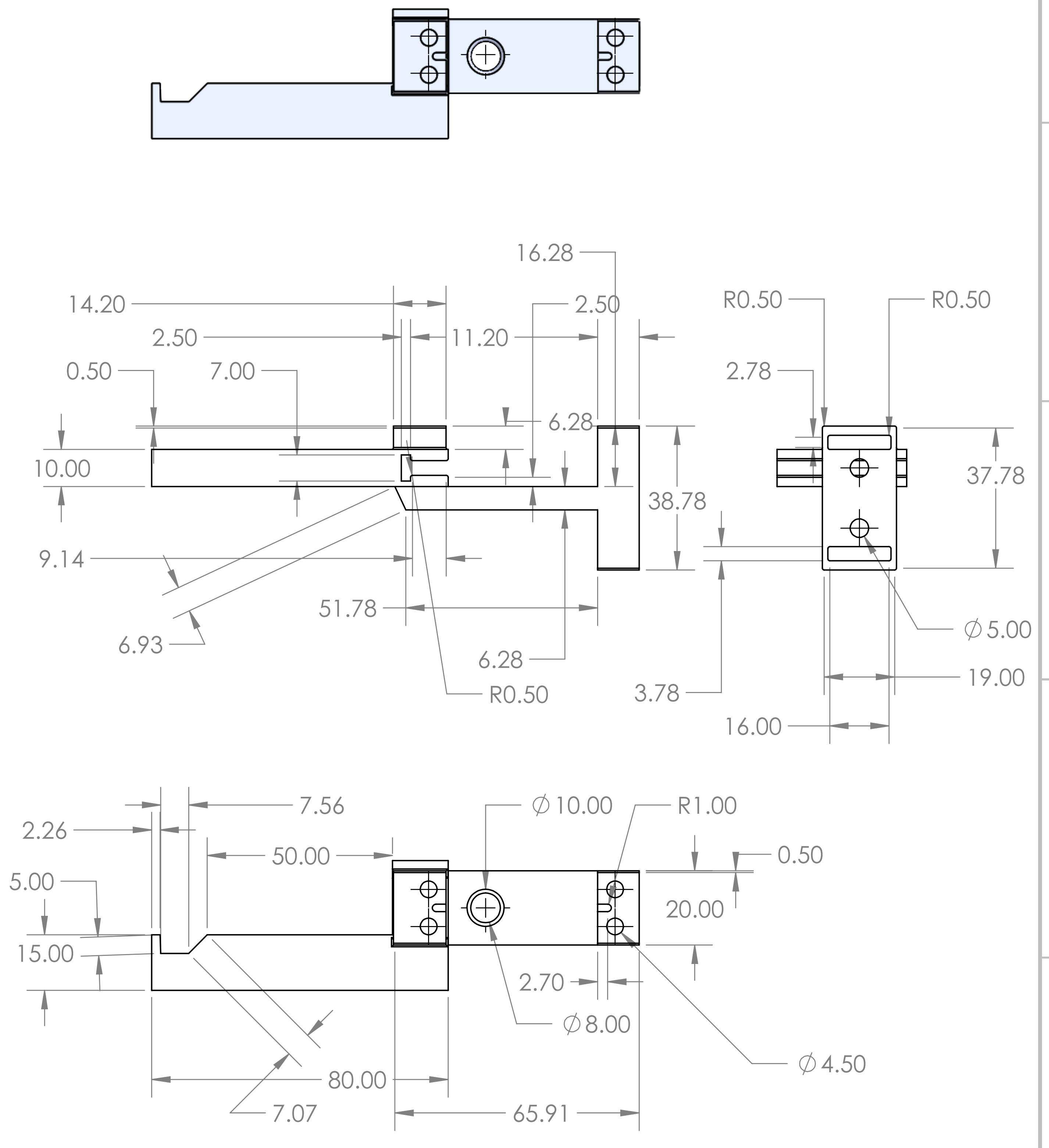

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CHK'D	Md. Shafiqul Islam	11/04/2023		
APPV'D	Md. Shafiqul Islam	13/04/2023		
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Name of the parts

Bottom finger

DWG NO.

ROV-01-01-04

A4

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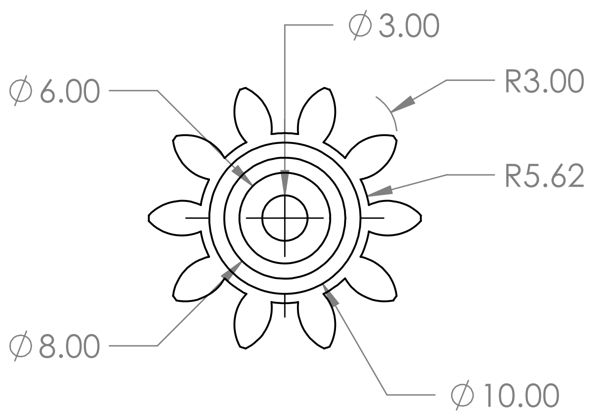

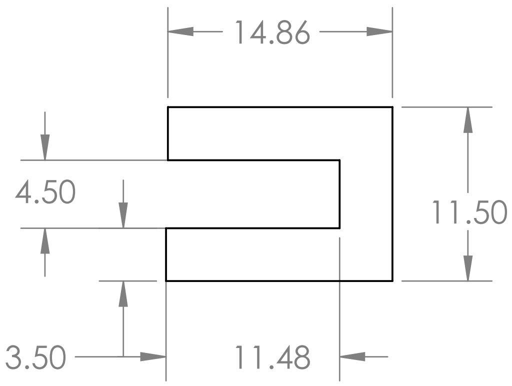

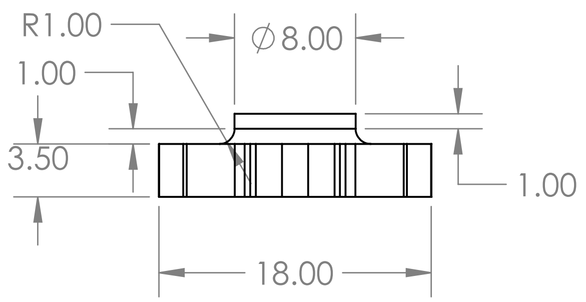

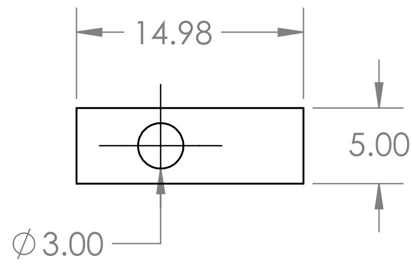

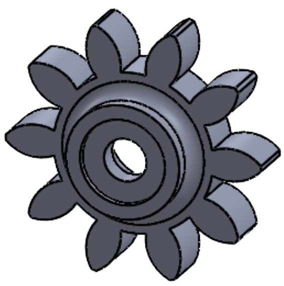

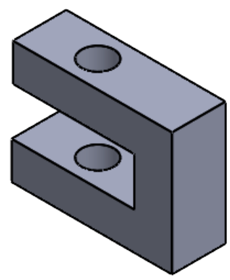

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APPV'D	Md. Shafiqul Islam	14/04/2023		
Q.A	1			

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Name of the parts

Pinion and extension

DWG NO.

ROV-01-01-05

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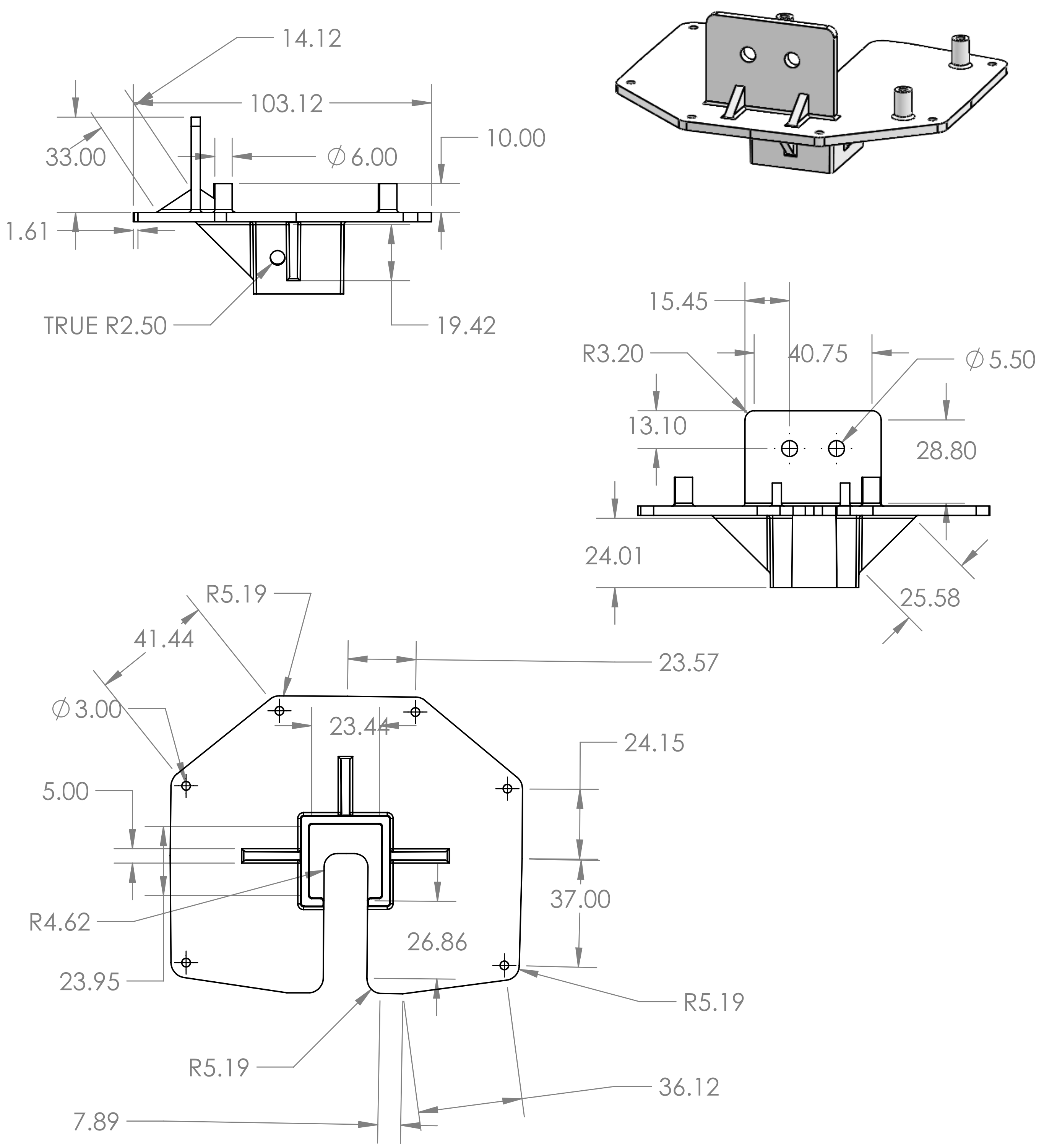

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Master in Mecatronic Engineering

Name of the parts

Gripper support

DWG NO.

ROV-01-01-06

A4

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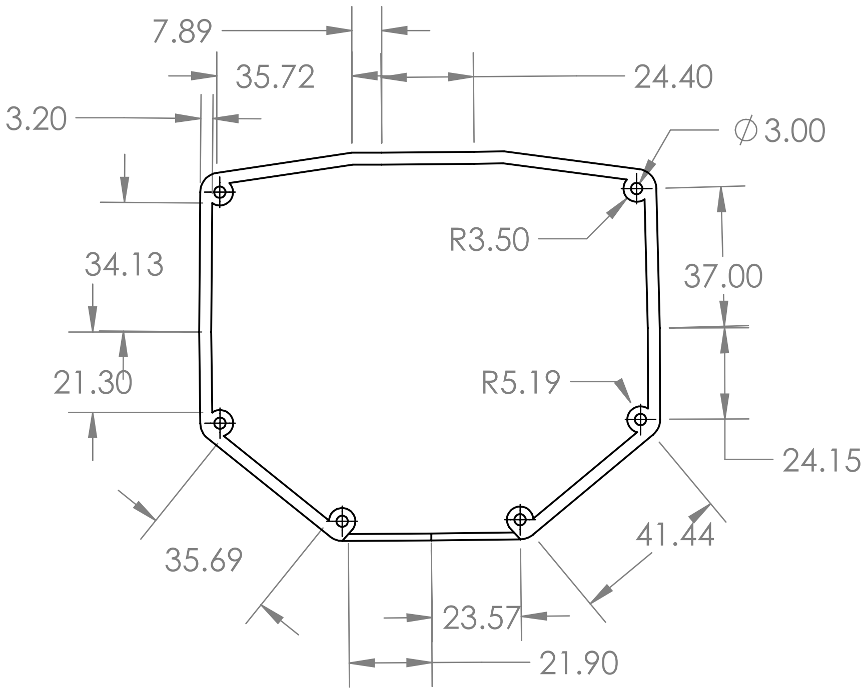

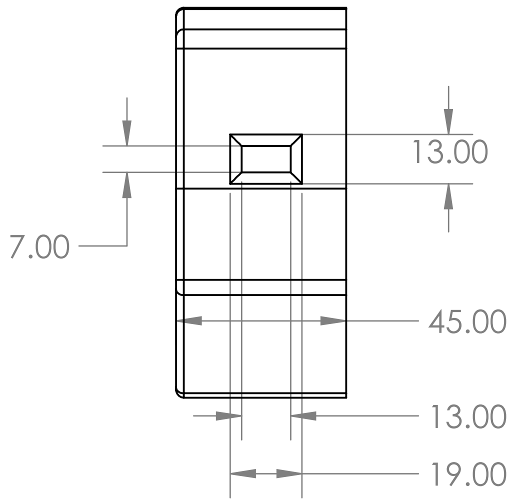

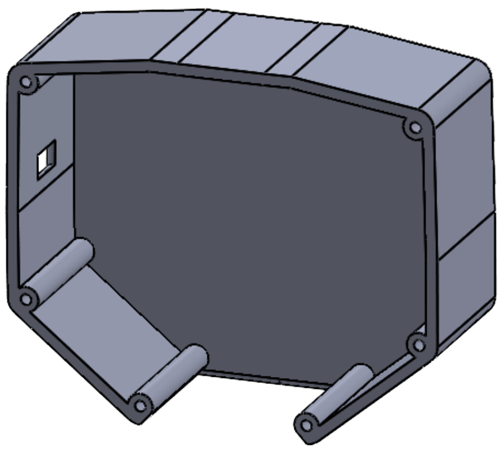

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APPV'D	Md. Shafiqul Islam	18/04/2023		
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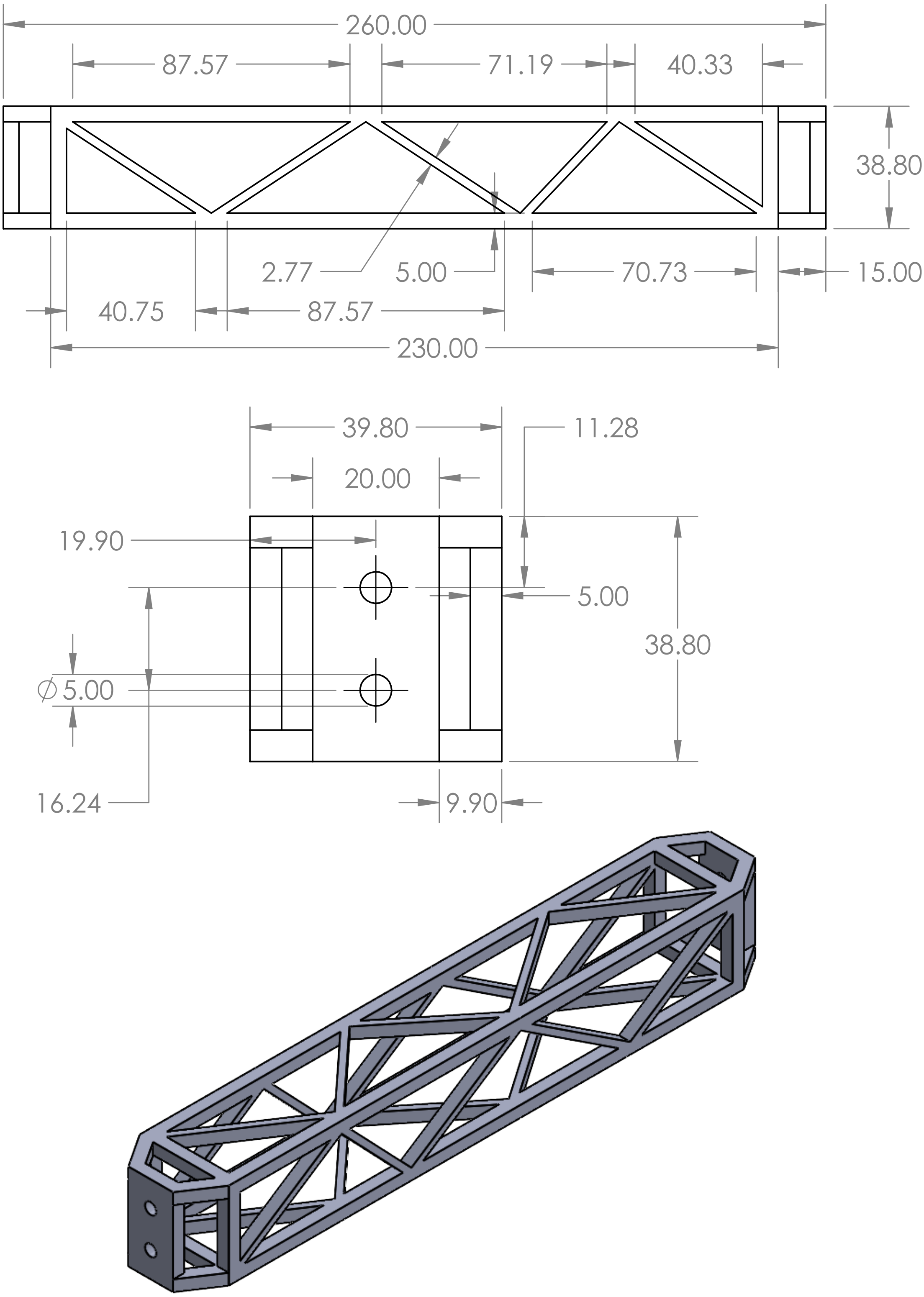

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APPV'D	Md. Shafiqul Islam	22/04/2023
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Master in Mecatronic Engineering

Name of the parts

Extended arm

DWG NO.

ROV-01-01-08

A4

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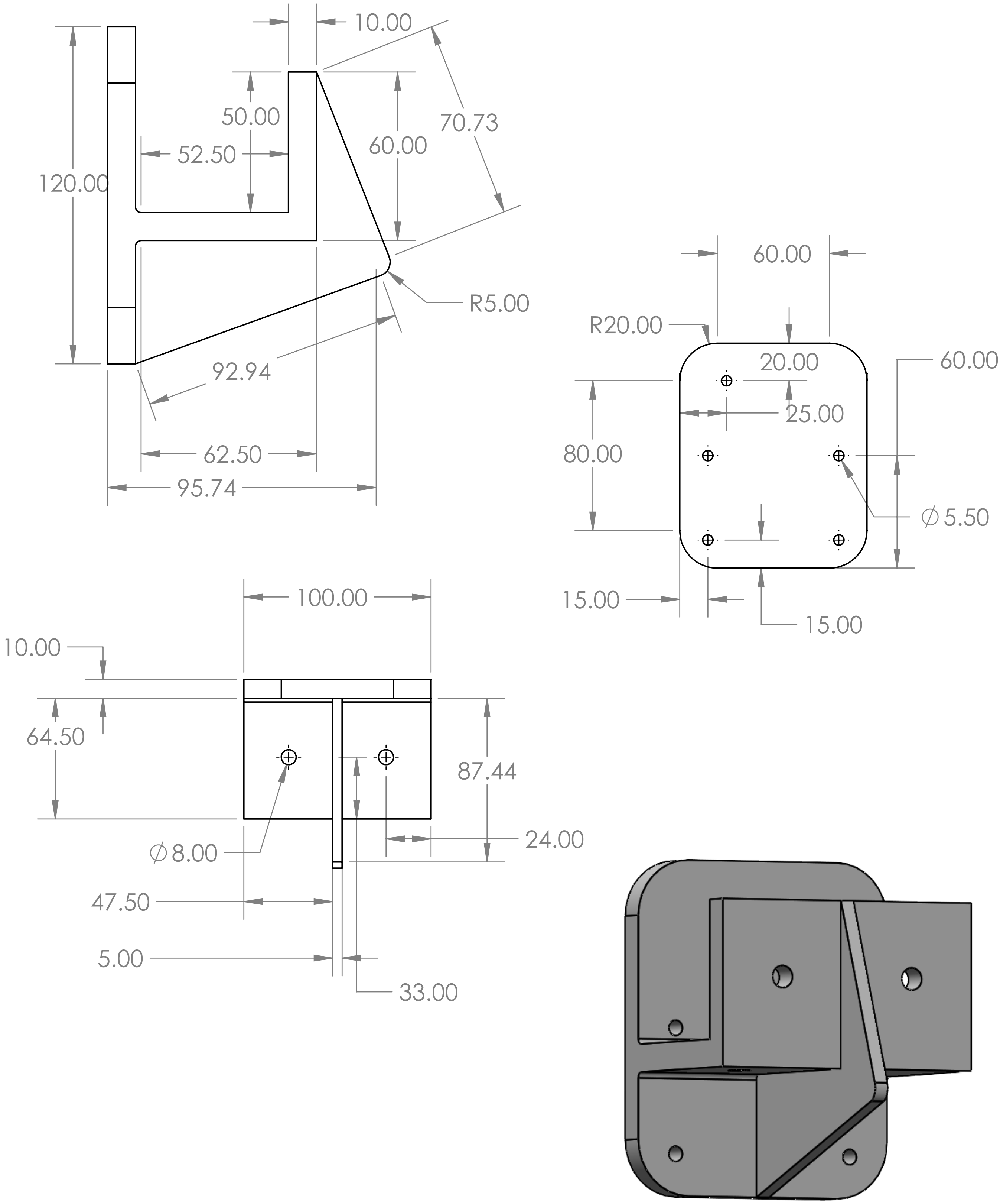

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CHK'D	Md. Shafiqul Islam	28/04/2023		
APPV'D	Md. Shafiqul Islam	02/05/2023		
Q.A	1			

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Name of the parts
Linear guide support

DWG NO.
ROV-01-01-09

A4

SCALE:1:2

MASTER IN MECHATRONIC ENGINEERING

Autonomous pick & place robot for electronic component drawers in their shelves

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ANNEX II – MECHANICAL SIMULATION

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Introduction

The purpose of this document is to provide a thorough explanation without exploring into excessively technical details of the machine's design and construction. It does this by detailing a number of calculations and design decisions whose resolution is more specific and, as such, should not be included in the main memory.

Analyses are conducted as follows:

- FEM-based structural analysis: ANSYS is used to conduct a finite element analysis to determine the resistance of the anticipated parts' areas that are thought to be crucial to the system's operation. This check will let us know if the design was successful or if we need to reconsider the parts have been designed

- Evaluation of plastic injection molding: This section will involve a study that simulates the injection procedure of multiple important Moldflow components to observe their behavior. These tests' outcomes will establish whether the parts' designs are suitable for 3D printing.

FEM-based structural analysis

This section examines the stresses experienced by the gripper and the extension of the gripper which will hold the gripper with the rover.

Gripper load carrying capacity analysis

For analysis the gripper the ABS material has been used as it is 3d printed parts. The mesh size has been used 1 mm for the whole body as the minimum dimension width is 10mm that is exactly 10% of it. The maximum capacity of the electrical component drawer is 3kg. So, the maximum applied load for the bottom finger will be 3kg. The load has been converted to force (F = m*g);

<u>Calculation:</u>

F = m*g;

Where, F is force in Newtons (N)

m is the mass in kilograms (kg)

g is the acceleration due to the gravity

We have,

m = 3 kg

g = 9.8 m/s^2

F = 3*9.8 N = 29.43 N

The Load distribution will be Vertical load which applies vertically to the bottom finger and the load is equal to the force of the electrical component drawer. The horizontal load represents the force required to prevent the gripper fingers form collapsing under the weight of the drawer. The force depends on the friction between the gripper fingers and the drawer, as well as the angle at which the fingers are positioned. The two fingers are perfectly vertical to each other so the horizontal force will be,

$$F_{horizontal} = F_{vertical} * \tan(\theta)$$

For this case the two fingers are parallel and angle between them is 90 degrees.

So, $F_{vertical}$ = 29.43N (weight of the drawer converted to force)

$F_{horizontal} \approx 0$ N (Negligible for vertical gripper fingers)

So, the Load has been put to the bottom finger 29.43N to see the stress and deformation of the finger.

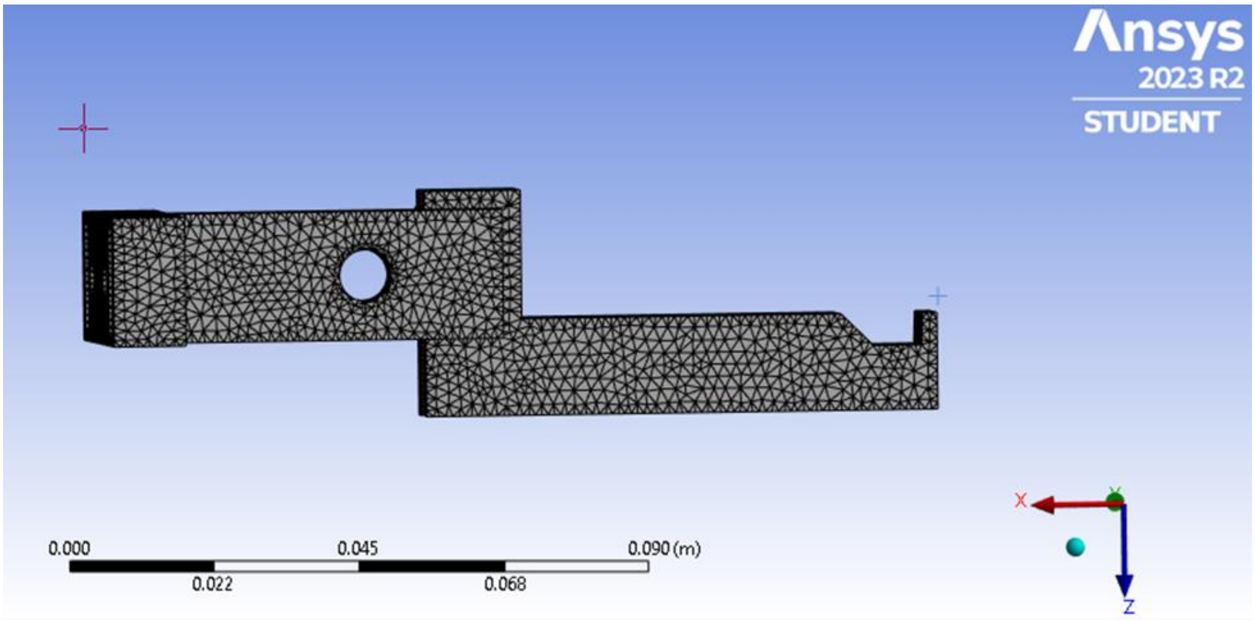

Figure 1 - Mesh generation of the bottom finger of the gripper

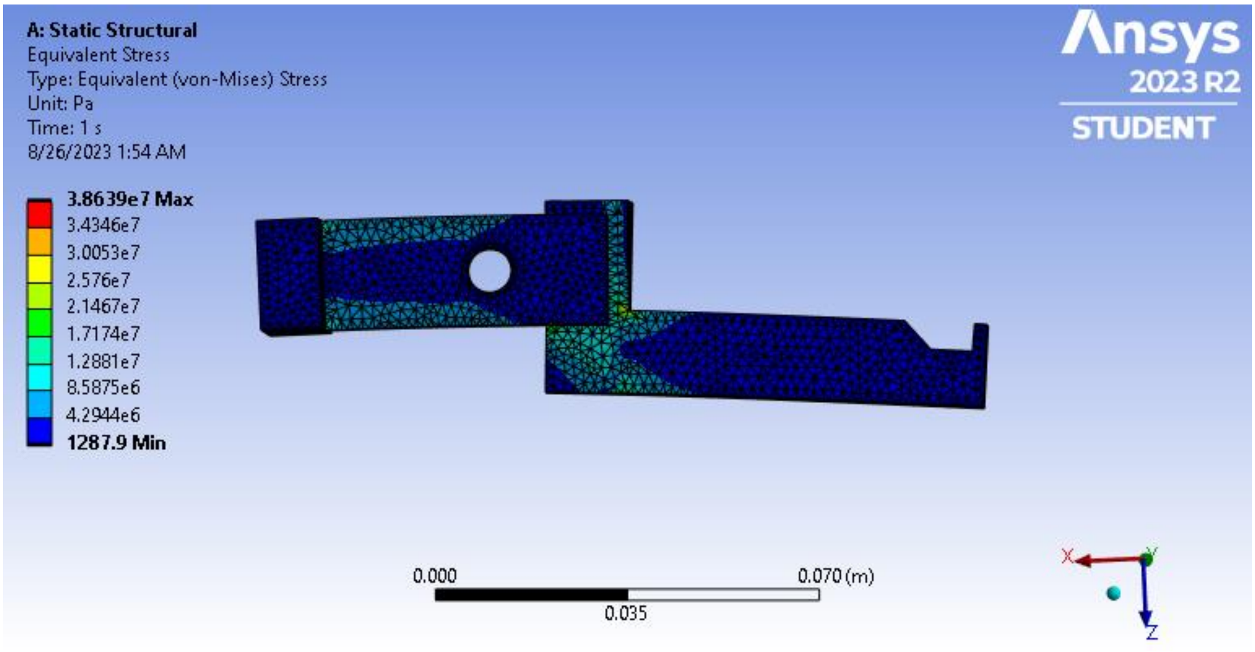

Figure 2 - Equivalent stress to the bottom finger of the gripper

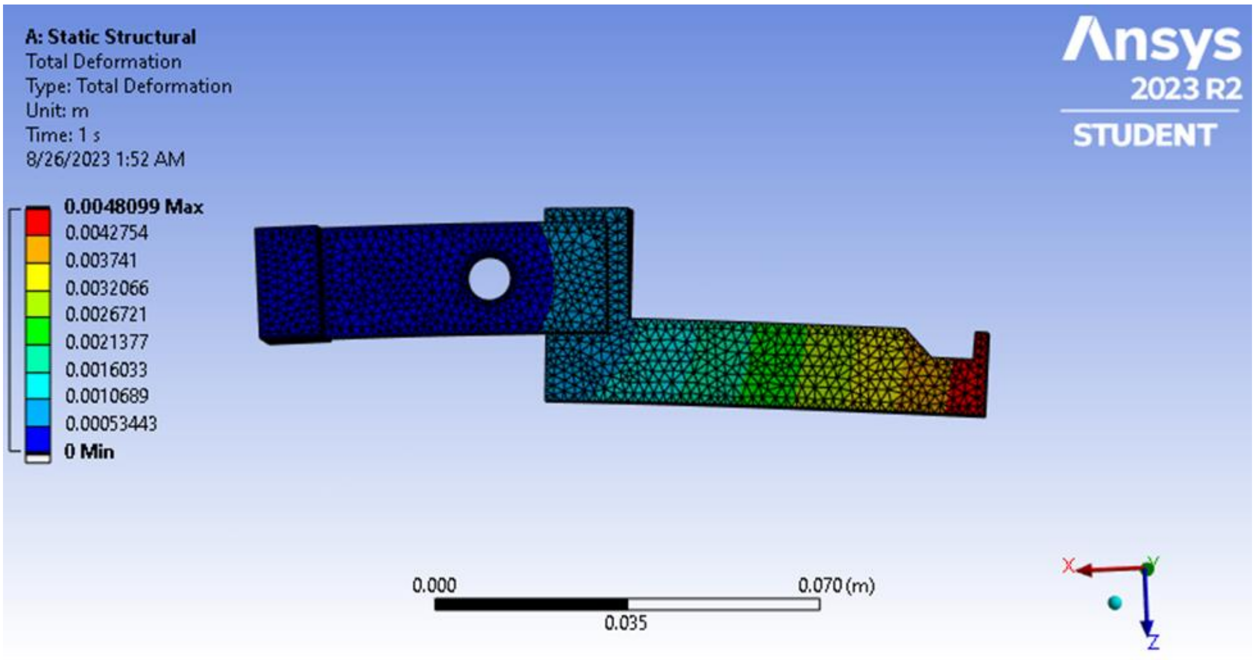

Figure 3 - Total deformation by the applied load to the bottom finger

Figure 1 shows the mesh generation for the bottom finger for analysis the mechanical properties. Figure 2 and figure 3 shows the stress distribution and total deformation for the input load.

Extended arm load carrying capacity with the gripper

For analysis the extended arm the load is as same as the gripper, because it will carry the same load as the gripper. Figure 4 shows the mesh generation for analysis the extended arm.

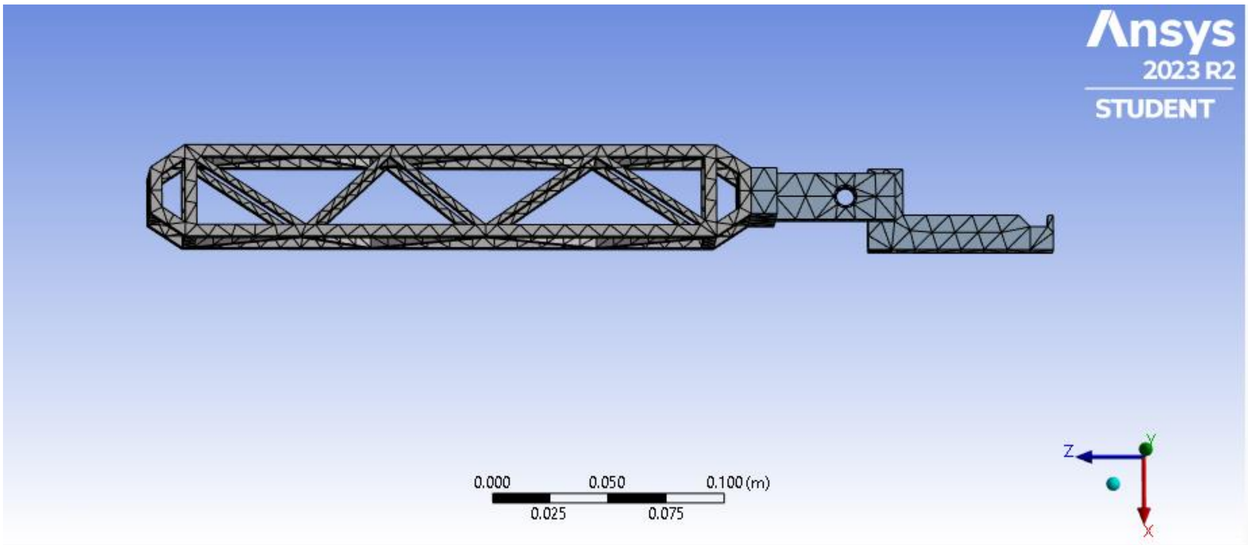

Figure 4 - Mesh generation of the extended arm with the gripper

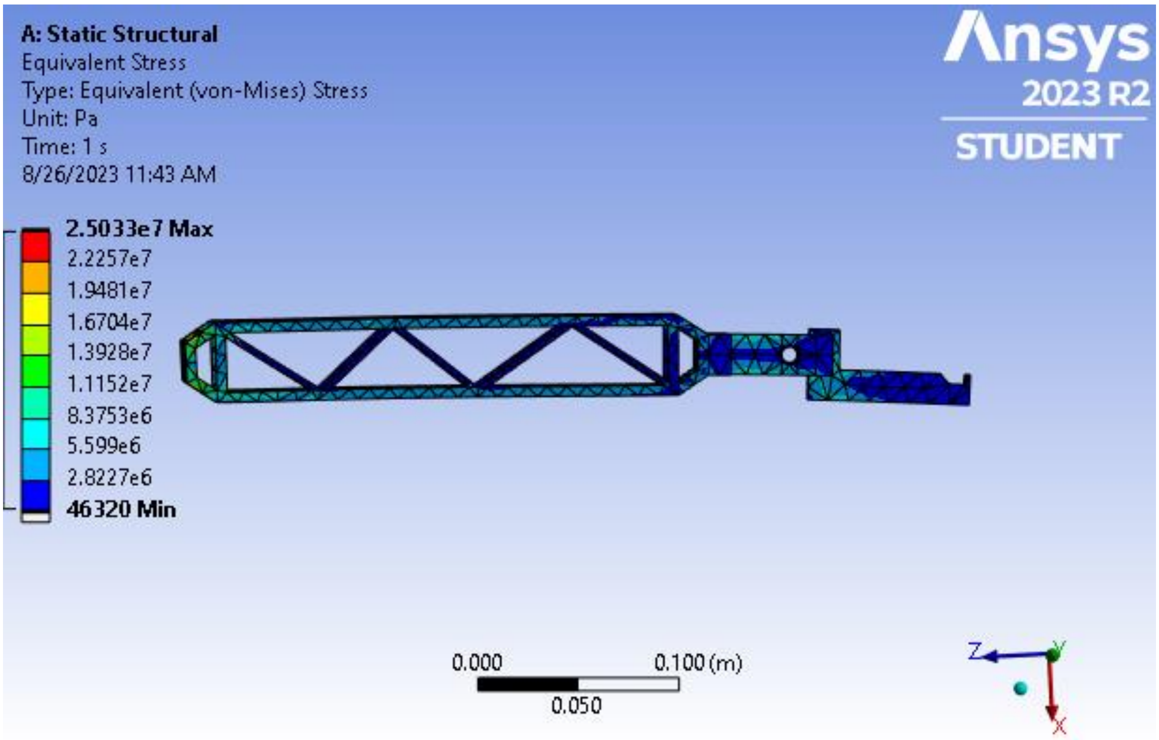

Figure 5 - Equivalent stress to the extended arm with the gripper

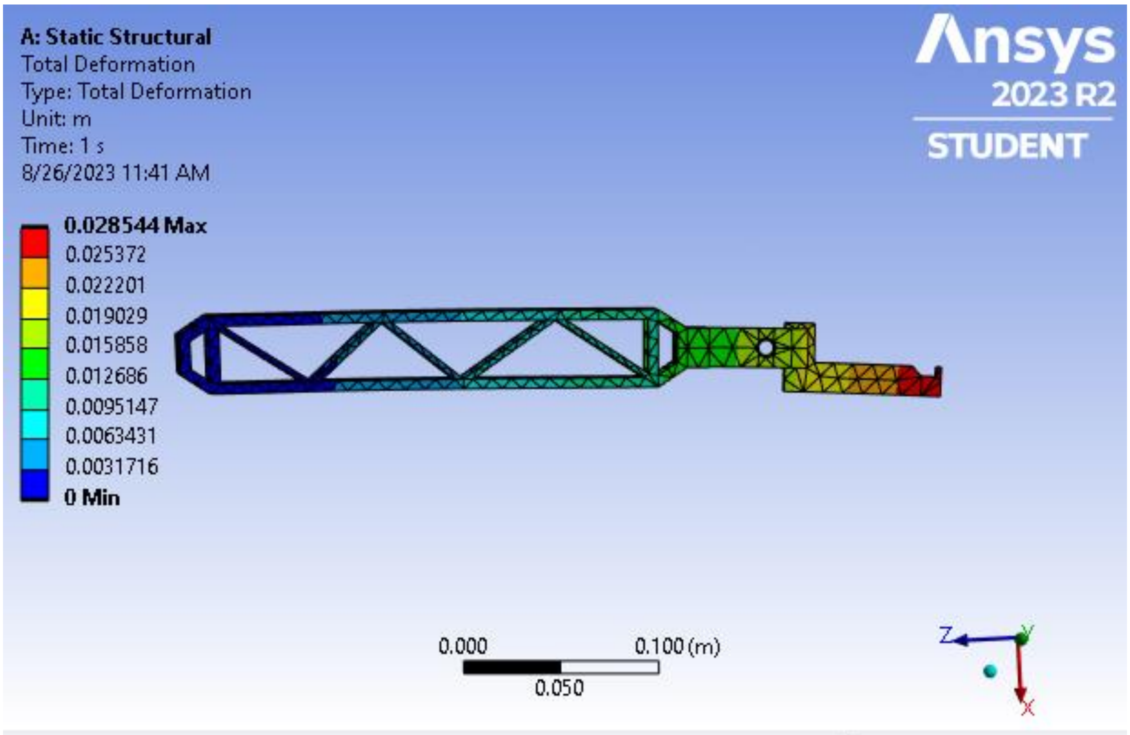

Figure 6 - Total deformation to the extended arm

Figure 5 and Figure 6 shows the Stress distribution and Total deformation of the extended arm.

Evaluation of plastic injection molding

This section contains the results of the plastic injection method's verification for various parts. The aim of this verification process is to confirm that the components fulfil the technical specifications and design requirements, and that there are no faults, within a permissible range, that could compromise their dependability and performance. The probable final quality of the parts, the sinkholes and air traps for the parts have been examined.

Quality Prediction

In accordance with the simulation, the part's quality relates to the level of quality that would be achieved by manufacturing it using the designated material: ABS HF380: LG Chemical

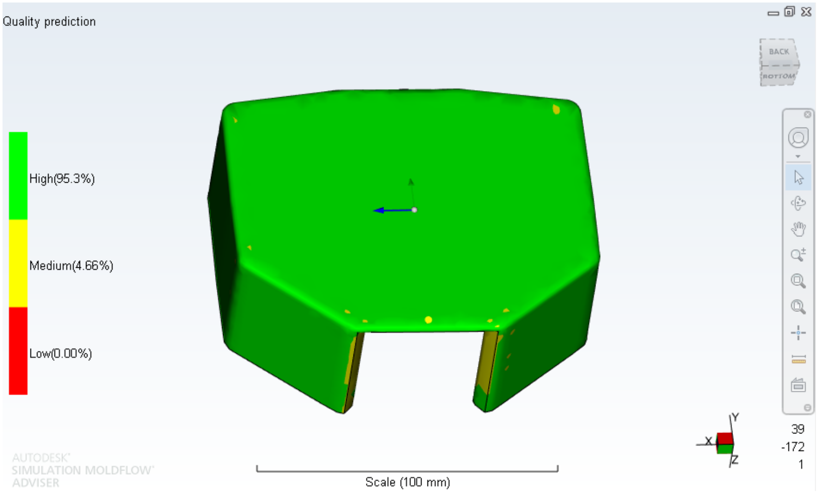

Figure 7 - Quality prediction of the gripper support (top)

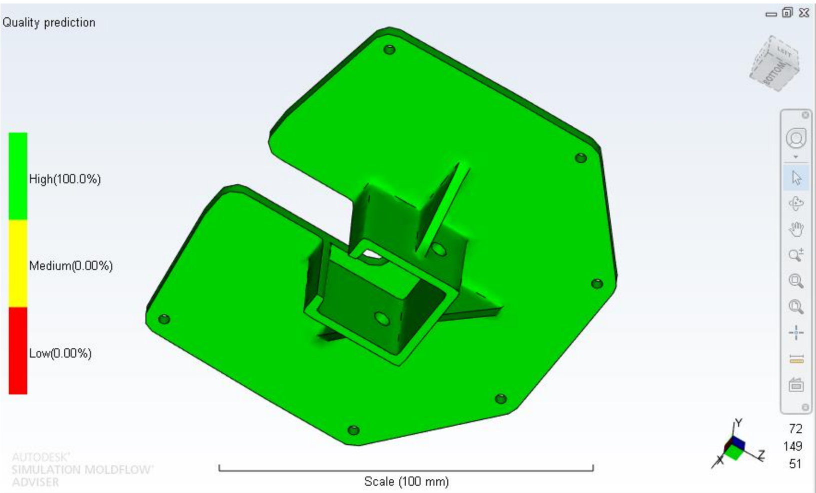

Figure 8 - Quality prediction of the gripper support

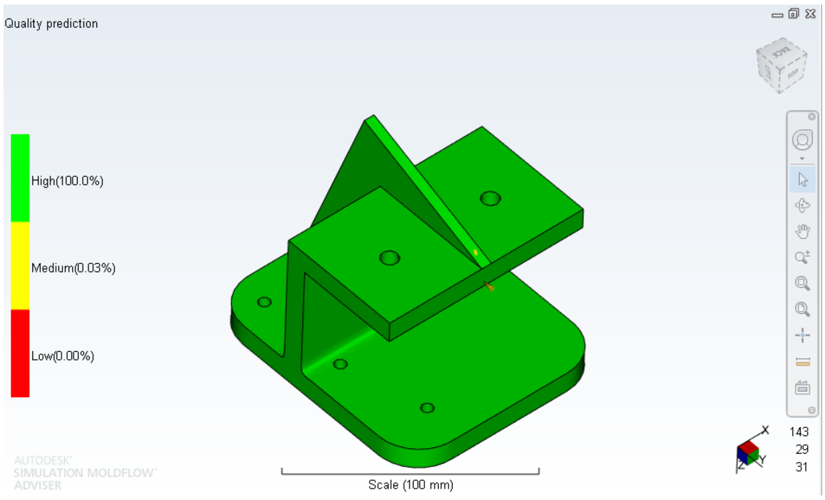

Figure 9 - Quality prediction of the linear guide support

From figure 7 it is seen that the quality is 96.3%. Figure 8 and 9 shows the gripper support and linear guide support has 100% quality prediction.

Sink Marks

In plastic injection parts, sinks often manifest as surface depressions on the molded object. These depressions can sometimes be highly noticeable and imperceptible to the unaided eye, but they can also occasionally be very tiny and have a detrimental effect on the piece's quality and look. In order to identify and address sinkage before the part is used in the finished product, it is crucial to perform a thorough visual inspection and measure the part's key dimensions.

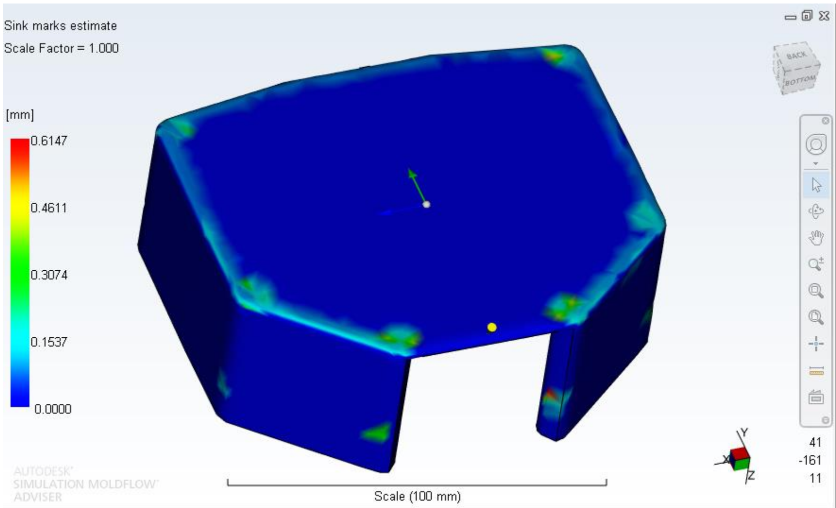

Figure 10 - Sink marks of the gripper support (top)

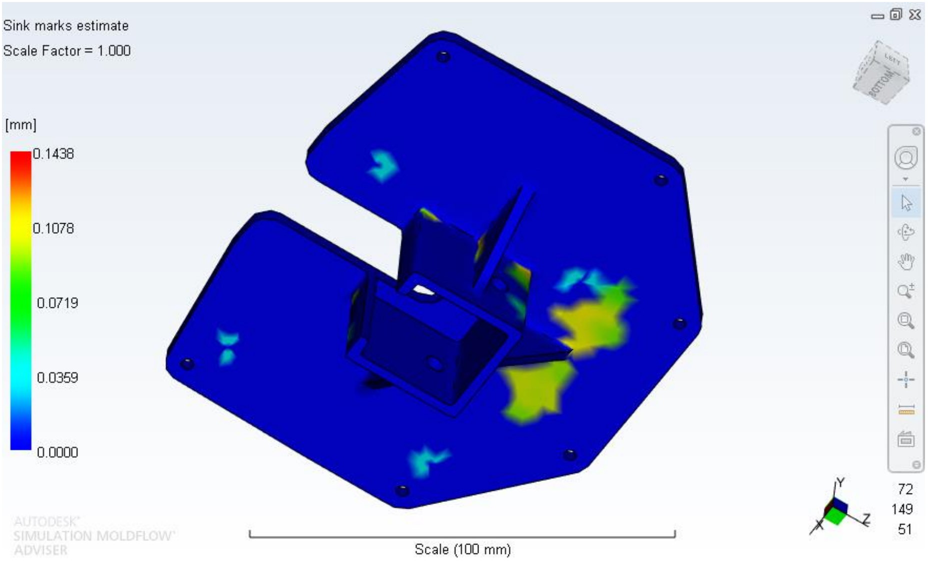

Figure 11 - Sink marks of the gripper support

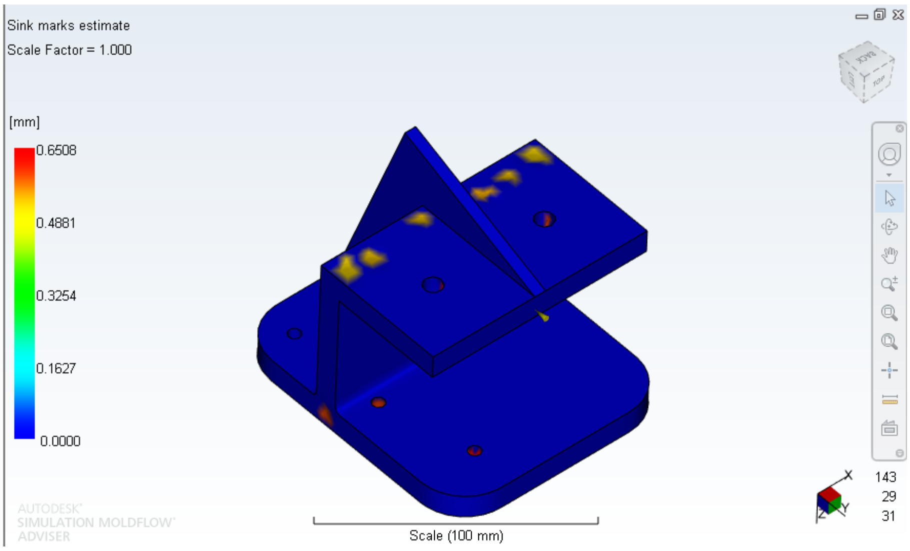

Figure 12 - Sink marks of the linear guide support

Figure 10, 11 and 12 shows the sink mark of the gripper support and linear guide support.

Air Traps

During the part manufacturing process, flaws called air traps might arise. Air gets trapped in the corners and empty spaces left by the plastic injection process because the plastic is unable to fully fill all of the holes and corners in the part. Strength, tightness, and the final piece's look could all suffer as a result, leading to portions with empty areas or structural weakness.

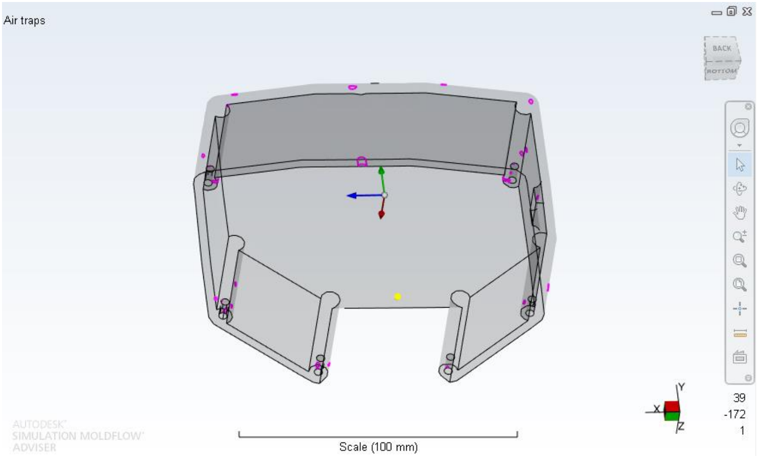

Figure 13 - Air traps of the gripper support (top)

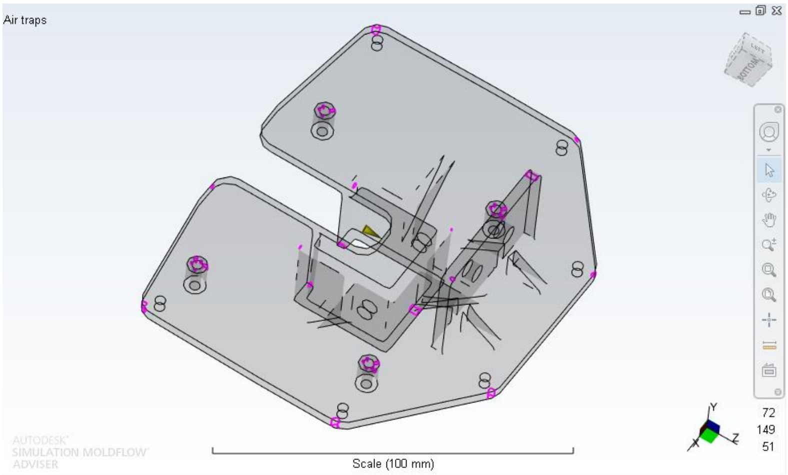

Figure 14 - Air traps of the gripper support

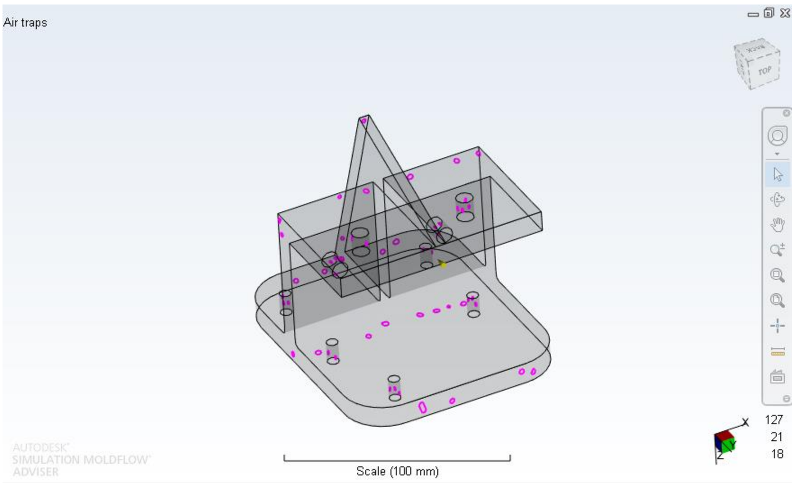

Figure 15 - Air traps of the linear guide support

Figure 13, 14 and 15 shows the air traps for the gripper support and linear guide support.

MASTER IN MECHATRONIC ENGINEERING

Autonomous pick & place robot for electronic component drawers in their shelves

TRABAJO FIN DE MÁSTER

ANNEX III – ELECTRICAL DESIGN

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Introduction

The rover's operations and functioning are largely supported by its electrical design. This complex system consists of a wide range of elements, each of which is essential to the rover's operation. Power distribution systems, microcontrollers, and processors coordinate the control and decision-making functions of the rover. The movements and interactions of the rover with its environment are made possible via actuators, such as motors and servos. Communication systems ensure real-time command and feedback capabilities by enabling seamless data interchange with operators or control centers. The rover's ability to carry out its mission and explore unexplored territory is made possible by the electrical design, a sophisticated mosaic of engineering, technology, and invention. This document provides the overall electrical layout for the master thesis.

Electrical design of the Rover

The electrical design for the whole rover is based on the power supply and connection established between each of the required components. The entire electrical design is divided into three parts, the main method for the whole rover. Then, inside this whole rover system, there are two more subsystems: one is the Gripper subsystem, and another one is the Linear guide subsystem.

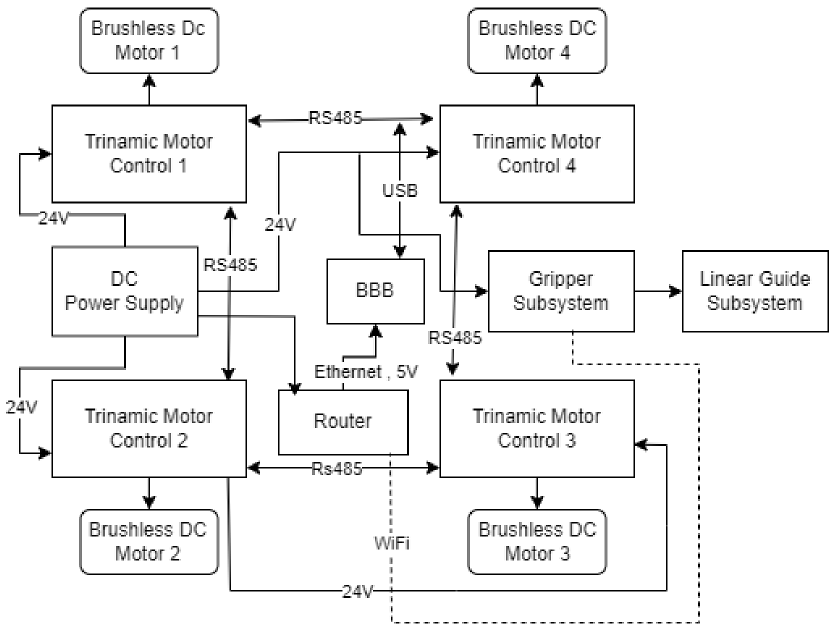

Figure 1 - Electrical design and connection between components of the rover

Figure 1 shows the main electrical design of the rover. It consists of the power distribution as well as the connection between different components. The main power supply provided to the rover is 24V, and then it is distributed through the different parts and subsystems of the rover. There are four brushless DC motor that operates at 24V. The four motors are connected to the four TRINAMIC motor controllers. The motor controller operates at 24V, and the main power supply provides this power directly. There is a router which is connected to the power supply. The BBB is connected by a USB cable with the router to power it up; this reduces the conversion of voltage for the BBB board. The gripper subsystem and linear guide subsystem are directly connected to the main power supply, and necessary conversion has been done in the subsystem. The Four motor controller is connected to each other by a USB connection. The communication is done by RS485 serial communication protocol. The BBB is associated with the router with the ethernet cable. A USB cable also connects the BBB to the motor controllers. The router establishes the communication between the gripper subsystem and BBB.

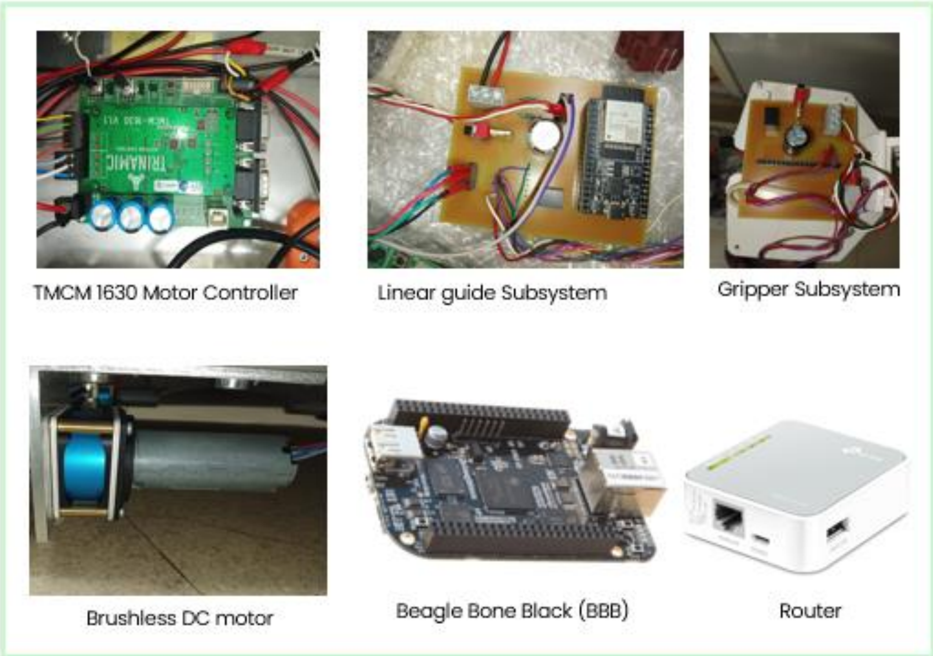

Figure 2 - Components of the rover

Figure 2 shows the different components of the rover.

Subsystem for Linear Guide Control

The subsystem for linear guide control is dedicated to the power management and establishment of communication between the components of the subsystem. The main element of this subsystem is the TMC2208 Motor driver, Stepper Motor, DC-DC converter, and ESP32.

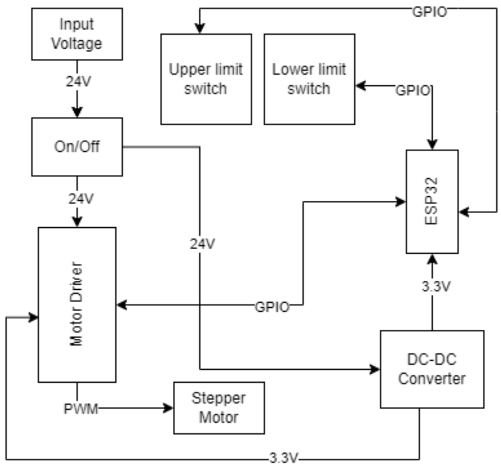

Figure 3 - Subsystem of Linear Guide Control

Figure 3 shows the connection between different components of the linear guide subsystem. The input voltage for the subsystem is 24V, and the motor driver takes two voltages: one is 24V to drive the motor and 3.3V for the logic control. The motor driver is connected to the stepper motor, and it sends PWM to the motor to rotate it clockwise or counterclockwise. The motor driver is also connected to the GPIO pin of the ESP32, which controls the logic for the motor driver. There is a DC-DC converter which converts the input voltage to 3.3V for the ESP32. There are also two limit switches to control the upper limit and lower limit of the movement of the linear guide. These two switches are connected to the GPIO pins of the ESP32.

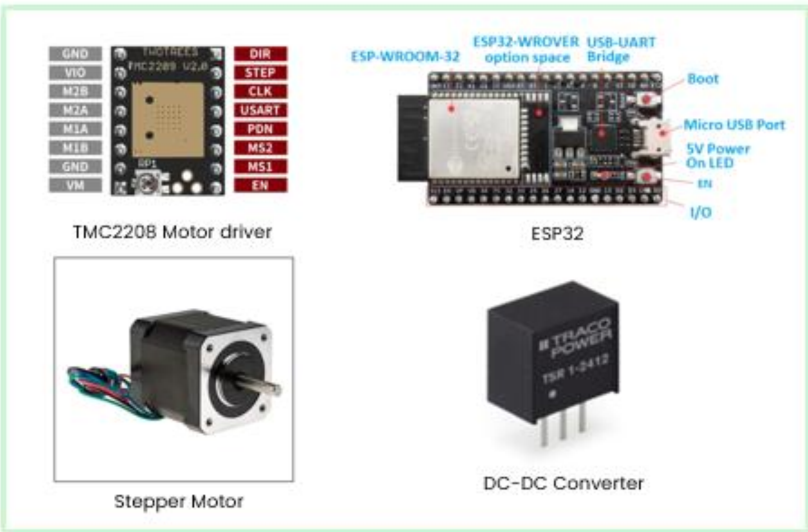

Figure 4 - Components of the Linear Guide Subsystem

Figure 4 shows the main components of the linear guide subsystem.

Subsystem for Gripper Control

The subsystem for gripper control is responsible for power management and for establishing communication between its parts. The Parallax Standard Servo (#900-

00005), ESP32, and TSR 1-2450E DC-DC converter make up this subsystem's primary parts.

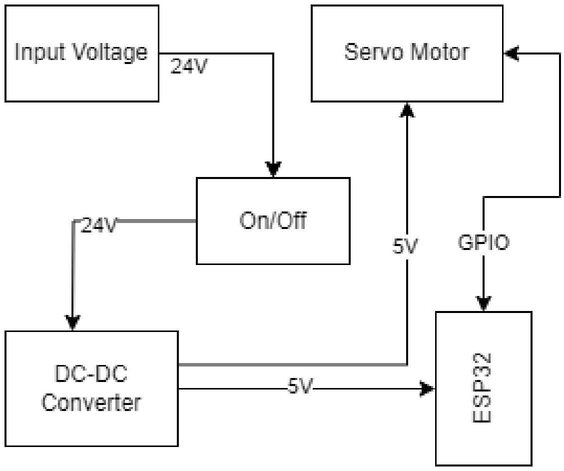

Figure 5 - Subsystem of the Gripper Control

Figure 5 shows the subsystem of the gripper control. This is a simple circuit to manage the power and control communication between the components. There is an on/off switch to control the power of the system. The input voltage for the system is 24V, and the DC converter converts the voltage to 5V and gives the output for the ESP32 and Servo Motor. The servo motor is also connected to the GPIO pin of the ESP32 to control the servo motor.

Figure 6 - Servo Motor for the Gripper Movement

Figure 6 shows the servo motor for the subsystem for gripper control.

Software Design of the Rover

A key component of the rover's functionality is its software architecture, which enables it to work independently and successfully in response to user guidance. This design includes a number of elements, such as user interfaces, communication protocols, control algorithms, and data processing. The software architecture is specifically designed to control data flow, decision-making, and task execution, assuring the rover's capacity to navigate, interact with its environment, and accomplish mission objectives. The rover's hardware components are coordinated by the software design in a crucial way that enables it to operate effectively and autonomously in a variety of difficult settings.

User Interface Design

The graphical user interface (GUI) created for this master's thesis is essential in simplifying user-rover system interaction and communication. The GUI consists of three windows, each of which performs a different task.

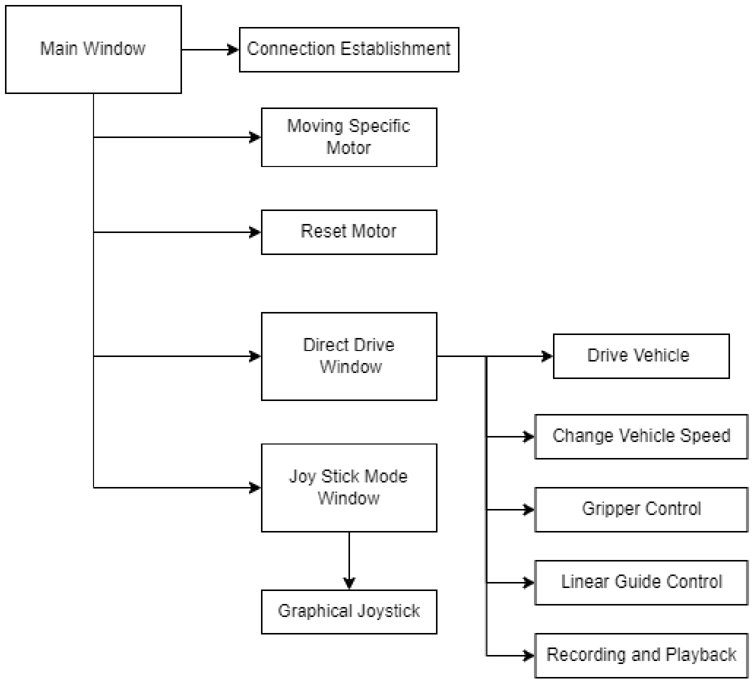

Figure 7 - User Interface Design

Figure 7 shows the user interface design of the rover. There is the initial window, which is the main window. These windows have different options. The Connection Establishment is the entry point for interacting with the rover system. Here, users can establish a connection with the server, which is essential for real-time control and data exchange. There are two sub-windows embedded within this window.

- Joystick Control: This sub-window provides users with a graphical joystick interface, enabling intuitive and real-time control of the rover's movements. By manipulating the virtual joystick, users can specify directional commands, such as forward, backward, left, and right.
- Drive Mode: The Drive Mode sub-window offers a comprehensive control panel for the rover's movement. It features ten distinct buttons for precise maneuvering in various directions. Additionally, a slider interface allows users to adjust the rover's speed dynamically. In the drive mode, there are multiple options to control the linear guide, gripper, and recording functions.

    - Linear Guide Control: Users can activate linear guide movements using dedicated buttons to move the linear guide up or down, facilitating tasks like shelf adjustment or object retrieval.

- Gripper Control: The gripper control section incorporates a slider for opening and closing the gripper mechanism. This functionality is crucial for object manipulation and retrieval tasks.

- Data Recording: Users can initiate and stop data recording sessions using two distinct buttons. This functionality allows for the capture of rover operations.

- Data Playback: This section offers playback controls for recorded data, enabling users to replay previous rover actions and analyze mission performance. Users can start, stop, delete, and pause recorded data playback.

- Data Saving and Loading: Users can save recorded data for future analysis and load previously saved data for review and further study.

Communication and Control Flow between Systems

The interchange of information and instructions between various parts or subsystems of a system is referred to as communication and control flow between systems. This allows the system to coordinate and function properly. The seamless operation of sophisticated techniques, such as robotics, automation, or networked applications, depends on this flow. The reliable, coordinated, and responsive operation of complex systems depends on the design of effective communication and control flows, which ultimately affects the functionality and efficacy of the system as a whole.

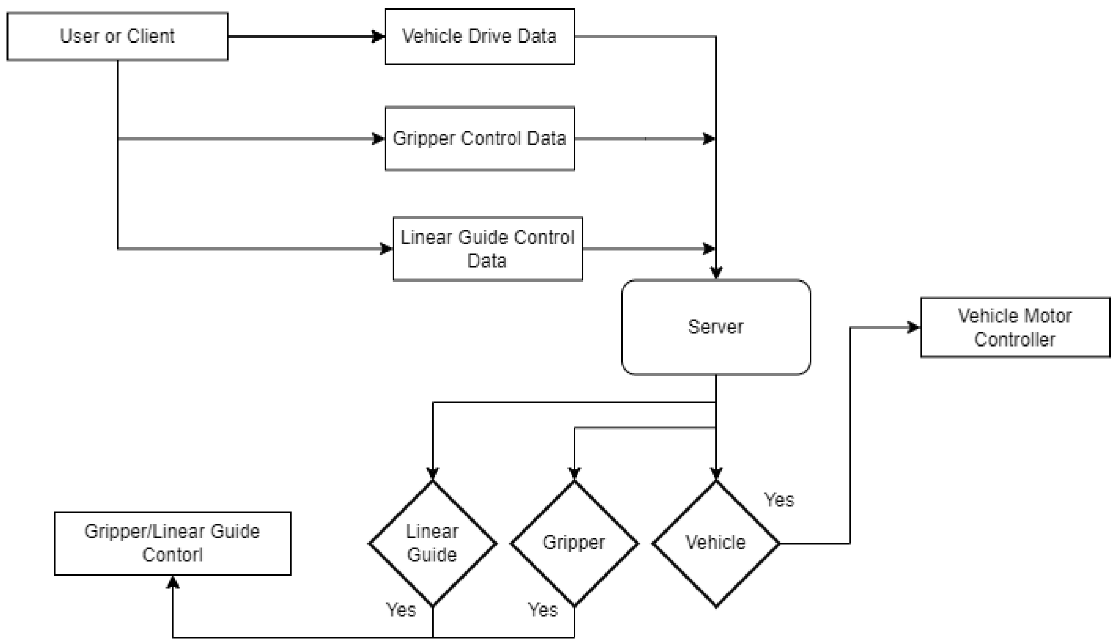

Figure 8 - Communication and Control Flow between Systems

Figure 8 shows the communication and control flow between different systems of the rover. The system components are,

- User/Client: The user or client serves as the primary interface for interacting with the rover system. They are responsible for sending control commands to the rover for various operations, including vehicle movement, gripper control, and linear guide control.

- Server: The server acts as an intermediary between the user/client and the rover's hardware components. Its main functions include receiving control data from the user/client, interpreting the type of control required (vehicle, gripper, or linear guide), and directing the data to the appropriate controller for execution.

- Controllers: There are two controllers on the system. The main controller or motor controller and Gripper and linear guide controller.

    - Motor Controller: This controller is responsible for managing the rover's movement. It receives vehicle drive data from the server and translates it into control signals for the rover's motors, ensuring precise and responsive action in accordance with user commands.

    - Gripper and Linear Guide Controller: The rover's linear guide system and gripper mechanism are controlled by the gripper and linear guide controller. The gripper controller operates the gripper mechanism as necessary by opening or closing it after receiving the gripper control data from the user/client that the server has identified. The server routes this data to the linear guide controller when it discovers linear guide control data coming from the user or client. The location of the linear guide is adjusted by the controller, enabling accurate vertical movement or modification as needed.

The communication and control flow of these systems are as follows,

- Data Transmission: Through a network connection and a communication protocol, such as TCP/IP, the GUI passes the user's control commands to the server. This information is sent from the GUI to the server.

- Data Interpretation: The server analyses the data after receiving the user's inputs to ascertain the necessary type of control, whether it be vehicle drive data, gripper control data, or linear guide control data. Based on established protocols or message formats, this interpretation.

- Control Dispatch: The data is routed to the appropriate controller once the server determines the type of control required:
    - If the data pertains to vehicle drive control, the server forwards it to the motor controller
    - The gripper controller receives the data if it has anything to do with gripper control.

    - The linear guide controller will get the data if it relates to linear guide control.

- Controller Execution: The server sends the control information to each controller, including the linear guide controller, gripper controller, and motor controller. They subsequently carry out the required tasks in accordance with the directions they were given.

- Rover Operations: The rover carries out the desired activities, such as moving, adjusting the gripper, or shifting the location of the linear guide, as a result of the controller's operations.