ABSTRACT

This project focuses on the development of an automated Pick-and-Place system using a 2-axis Cartesian robot designed specifically for handling IB (Insulating Base) plates. The system uses horizontal (X-axis) and vertical (Z-axis) movements driven by stepper motors to ensure precise linear positioning, while a linear gripper securely picks and places the plates. The robot is built on a lightweight aluminium frame and follows a structured engineering design process—starting from problem identification to component selection, layout planning, and prototype testing. Engineering exploration guided the choice of motion systems, sensors, and gripper mechanisms, while Design Thinking ensured the solution addressed key issues in manual plate handling such as inconsistent placement, slow operation, and labor dependence. The result is a mechanically simple yet highly effective automation system that delivers consistent, accurate, and repeatable performance. The prototype was tested for movement accuracy, gripper reliability, and synchronized control. This project not only automates a repetitive task but also provides a practical learning opportunity in robotics, offering insights into real-world applications of sensor integration, motion control, and automation design using a Cartesian robot platform tailored for industrial tasks.

1. INTRODUCTION

The engineering design process for developing a Pick-and-Place system using a Cartesian robot with X and Z axes for handling IB plates is a structured and iterative approach that ensures precision, efficiency, and reduced human intervention. This process guides the project from identifying the core problem to developing and refining a functional prototype, integrating both Engineering Exploration and Design Thinking for Automation to create a user-focused and high-performing solution.

Engineering exploration involves researching automation components such as stepper motors for precise linear movement along the X and Z axes, and linear grippers for secure plate handling. Since the robot operates on two axes horizontal (X) and vertical (Z) the system is mechanically simpler, yet still capable of achieving reliable pick-and-place functionality. Exploration also includes studying existing Cartesian systems to optimize component integration and motion control for smooth operation.

Design Thinking for Automation applies a human-centered approach to address challenges faced in manual plate handling, including inconsistencies, inefficiencies, and the need for constant labor. By understanding these issues, the system is designed to automate the process, ensuring faster, more accurate, and repeatable placement of IB plates. This method ensures that the final system not only meets technical requirements but is also user-friendly and efficient.

Minor projects based on this setup offer hands-on experience in robotic automation, involving the design and assembly of a working prototype. These projects help students understand practical aspects of mechanical design, sensor integration, and control programming, enabling them to translate theoretical concepts into real-world applications.

The design process begins with problem identification, analyzing the drawbacks of manual IB plate handling—such as uneven placement, slow operation, and labor dependency—and defining the need for automation. Once the problem is established, the project goals are set, including automating the pick-and-place task using a 2-axis Cartesian robot, integrating a linear gripper, and using sensors for precise detection and placement of the IB plates.

During the engineering design phase, the system layout is conceptualized to ensure stable and synchronized motion along the X and Z axes. A linear gripper is chosen for effective gripping and release of plates, while the control system is developed to coordinate motor movement and sensor feedback. This phase focuses on creating a smooth and collision-free workflow for the robotic arm.

In the prototype development phase, all components are assembled into a functional system. The Cartesian structure is built, sensors are calibrated, and the gripper is tested for reliable operation. The prototype undergoes trials to check movement accuracy, pick-and-place consistency, and overall system coordination. Based on test results, adjustments are made to enhance performance and achieve a robust and reliable automated system. This structured process ensures the creation of a simple yet effective pick-and-place solution using a 2-axis Cartesian robot tailored for IB plate handling.

2. LITERATURE SURVEY

[1] Mistikoglu and Özyalçin (2010) developed a Cartesian robot with three degrees of freedom for industrial tasks, focusing on speed, precision, and modular design. Their system integrated mechanical, electronic, and software components in parallel, ensuring smooth motion and easy testing. The study highlights the benefits of using Cartesian robots in educational and industrial settings, which directly supports the design approach used in our Pick-and-Place project.

[2] Jaiswal et al. (2020) developed a low-cost Cartesian pick-and-place robot designed for small and medium-scale industries. The robot used NEMA17 stepper motors, GT2 timing pulleys, and a servo gripper, with all axes driven by belt mechanisms. Controlled using Python and Arduino Mega, the system achieved good accuracy (~0.2 mm) and a speed of 1 m/min. The design focused on affordability, simplicity, and ease of integration. Their methodology and component choices provide valuable insights for developing cost-effective Cartesian robots with reliable motion control and gripper functionality.

[3] Kim et al. (2025) introduced the Linkage-Belt Hybrid (LBH) gripper for dish-collecting robots to address challenges posed by varying dish shapes and sizes. Combining rigid linkages and soft silicone belts, the LBH gripper ensures adaptive and stable grasping, outperforming bar-type, linkage, and soft grippers in experiments. The hybrid design allows both gripping and non-gripping actions, such as pushing dishes. Structural simulations and experiments confirmed its superior payload capacity, safe dish handling, and reliability in real-world restaurant tasks, making it a promising solution for service automation applications.

[4] Civelek and Fuhrmann (2023) developed a 6-DOF Cartesian robot controlled through a mixed reality interface using sense gloves and virtual control buttons [Paper 4]. The system allows remote operation of tasks like screwing and unscrewing bolts with enhanced realism through haptic feedback. Unity 3D and Arduino were used to synchronize the robot's physical motion with virtual hand gestures. Stepper motors and color-coded work boundaries ensured safe and precise operation. This study emphasizes immersive human-robot interaction for industrial and educational applications. The integration of MR with Cartesian control offers a new layer of interactivity and realism in robotic automation.

[5] Funda et al. (1996) introduced a constrained Cartesian motion control strategy for teleoperated surgical robots working in limited and sensitive environments [Paper 5]. Their method optimizes robot movement using a constrained quadratic optimization approach, ensuring precision and safety even with kinematically deficient systems. The system was implemented on an 8-DOF surgical robot (PLRCM) and tested in laparoscopic scenarios. It effectively handled both redundant and deficient configurations using uniform control logic. The formulation allowed strict motion constraints, real-time performance, and dynamic task-space adjustments. The system was successfully validated through preclinical trials at Johns Hopkins Medical Center.

[6] Nguyen et al. (2023) developed a 4-DOF SCARA robot arm integrated with a computer vision system for palletizing tasks. The system uses a novel method to estimate 3D coordinates of objects using pixel data without needing traditional camera calibration. Stepper motors and a vacuum gripper were used for precise pick-and-place operations. The robot achieved an

average accuracy of 0.5 mm and a cycle time of 2.8 seconds per object. Image processing was performed using HSV thresholding and Otsu's method. This study demonstrates how vision-guided SCARA robots can automate industrial sorting with high precision and speed.

[7] Pham (2019) investigated the position control of a 3-axis Cartesian robot developed using Festo components [Paper 8]. The study focused on precise axis control through Siemens S7-1500 PLCs, Sinamics G120 drives, and incremental encoders. The system was designed for accuracy of 0.1 mm per movement unit, using PID tuning and motion profiling via TIA Portal. Although the experimental validation faced hardware communication issues, the theoretical framework and calculations were sound. This work provides critical insight into closed-loop control, encoder feedback, and networked drive coordination for Cartesian robots.

[8] Soft robotic grippers have gained significant attention for their adaptability and safe handling of varied objects. Shintake et al. (2018) provide a comprehensive review of advancements in gripper technologies, highlighting the use of soft materials like elastomers and shape memory alloys that offer compliance and precision. These materials enhance the robot's ability to grip delicate or irregularly shaped items, making them ideal for automated handling applications. Incorporating such soft grippers into Cartesian robotic systems can improve flexibility, safety, and object adaptability in industrial environments like IB plate handling systems (Shintake et al., 2018).

[9] Robotic grippers play a crucial role in automation by enabling precise and adaptable object handling. Telegenov et al. (2015) presented a low-cost, open-source 3D-printed three-finger robotic gripper suitable for educational and research applications. The gripper uses an underactuated mechanism driven by a single actuator, enabling it to handle objects of various shapes and sizes. Its modular design, compatibility with off-the-shelf components, and adaptability through 3D printing make it an efficient and accessible solution for industrial tasks. Such gripper platforms can be integrated into Cartesian robotic systems to enhance automated handling performance and system flexibility.

[10] Sadun et al. (2020) present an open-loop grasping analysis for a 3-Finger Adaptive Robot Gripper, focusing on real-time monitoring of finger position and grasping force using motor encoders, current sensors, and force-sensing resistors (FSR). The study introduces a modified 3D-printed plastic cover to enhance FSR sensitivity, enabling more accurate force detection, especially for soft objects. Experimental results show that the gripper adapts its grasp based on object stiffness, with significant relationships observed between finger position, motor current, and force sensor data. These findings support the gripper's utility for precise, stable manipulation in advanced robotics applications

[11] Kaur and Kim (2019) address the limitations of traditional soft robotic grippers by introducing a 3D-printed architectured cellular finger design using auxetic structures. Their approach combines lightweight, mechanically durable, and compliant materials, overcoming issues of insufficient stiffness and durability found in conventional elastomer-based grippers. The integration of pressure sensors and multi-material 3D printing allows for a single-step fabrication of functional, repeatable, and reliable gripper fingers. The resulting gripper demonstrates a maximum gripping force of 16 N and adaptability to various objects, significantly broadening the application space of soft robotic systems.

[12] Rahman et al. (2024) developed a three-finger adaptive robotic gripper designed to assist individuals with upper limb dysfunctions in performing Activities of Daily Living (ADLs). The gripper, manufactured using 3D printing, features both grasping and pinching capabilities with adaptive force control, enabling it to handle 90 essential ADL objects of varying shapes, sizes, weights, and textures. Usability and load tests demonstrated successful manipulation of 75 out of 90 objects, with weights up to 2.9 kg and object sizes up to 80 mm. The study highlights the gripper's potential to enhance independence and quality of life for users.

[13] Kim et al. (2025) introduce the Linkage-Belt Hybrid (LBH) gripper, designed for dish-collecting robots in restaurant environments. By integrating a linkage structure with soft silicone belts, the LBH gripper achieves both adaptability and structural support, enabling secure grasping of dishes of various shapes and sizes. Experimental results show the LBH gripper outperforms traditional bar-type, linkage-adaptive, and soft grippers, successfully grasping the highest number of objects and demonstrating high payload capacity (up to 10 kg for bowls). The hybrid design also ensures safer handling and stable non-grasping operations, making it suitable for service robotics applications.

[14] Yamada and Mitsuda (2021) propose a novel vacuum-driven, ring-shaped soft robotic gripper capable of gently and securely handling objects of various shapes. Unlike conventional fingered or bag-type grippers, their design uses a flexible tube with laminated sponges and plastic sheets, which contracts upon air evacuation to encircle and stabilize objects without slippage or excessive pressure. The gripper's adaptability, adjustability of gripping force, and increased rigidity after contraction make it suitable for fragile and irregularly shaped items. Experimental results demonstrate its effectiveness and potential for diverse applications in automation and robotics.

[15] Gil Fuster (2015) presents a comprehensive study on the design and development of a modular robotic gripper tailored for the Fable system. The thesis reviews various gripper classifications, kinematic and drive mechanisms, and state-of-the-art industrial and hobbyist designs. Two gripper prototypes were developed and tested, focusing on adaptability, force measurement, and control strategies. Experimental results demonstrated that the modular design enabled effective grasping of diverse objects, while integrated sensors improved manipulation accuracy. The research highlights the importance of modularity, sensor integration, and control flexibility in advancing robotic end-effector technology.

[16] Chouhan et al. (2014) present the design and fabrication of a stepper motor-controlled robotic gripper intended for industrial applications such as handling small, regular-shaped objects. The prototype features one degree of freedom each for linear and rotational motion, achieved through a linear actuator and DC motor-driven gear assembly. Emphasizing simplicity, low cost, and reliability, the gripper's modular design allows for easy adaptation of end effectors to suit different object shapes. Kinematic analysis and torque calculations ensure appropriate motor selection. The study demonstrates the gripper's effectiveness for pick-and-place tasks, highlighting its industrial applicability and design flexibility.

[17] Universal grippers offer a flexible and efficient solution for handling various objects without needing a separate gripper for each task. Reddy and Suresh (2013) emphasize the importance of universal grippers in industrial robotics, highlighting their ability to conform to objects of different shapes and materials using adaptive mechanisms. Unlike rigid grippers, these systems can mimic human hand functions more effectively, reducing complexity and

improving operational versatility. Integrating such grippers into Cartesian robots enhances automation reliability and broadens the range of applications in part handling and assembly tasks.

[18] Widhiada et al. (2015) present the development of a five-fingered robotic gripper using robust PID control and simulation tools like MATLAB/Simulink and Inventor. The study highlights the importance of accurate motion control in robotic fingers to mimic human-like dexterity. Through simulation and prototyping, the gripper achieved stable, low-error angular positioning. This research supports the integration of controlled gripper systems in automation applications. For IB plate handling using a Cartesian robot, such PID-based control techniques can improve grip accuracy, reduce overshoot, and ensure consistent placement, especially in precision-dependent industrial tasks.

[19] Rateni et al. (2015) developed a soft robotic gripper made entirely of elastomeric materials to safely manipulate delicate objects. Their under-actuated design, inspired by biological models like the octopus, uses cable-driven fingers to conform to object shapes without complex sensing or force feedback. The gripper shows promise for medical applications due to its compliant structure and safe interaction properties. Such a design approach can be translated to industrial automation, including Cartesian robot-based plate handling, where safe, adaptive gripping is critical for handling components of varying shapes without causing damage.

[20] Hussain et al. (2020) proposed a modular soft–rigid tendon-driven gripper using interpenetrating phase composites (IPCs) with tunable stiffness. By integrating 3D-printed soft joints and rigid links, they achieved adaptable gripper performance through variable material reinforcement. The modular design supports interchangeable fingers and configurable grasping modes, such as power and pinch grasps. This research highlights the advantage of customizing joint stiffness to match specific tasks. Applying such a gripper in a Cartesian robot system handling IB plates can enhance object adaptability, grip control, and efficiency while reducing complexity and the need for multiple gripper types.

[21] Robot-based mating of electrical connectors remains challenging due to geometric uncertainties and filigree tolerances. Traditional methods often focus on either grasping or mating separately without addressing the effect of in-hand pose variability. Prior work proposed automatically designed gripper jaws with configurable clearance to improve grasp robustness [Gebauer et al., 2023]. Building on this, Gebauer et al. (2024) experimentally validated that sensitive joining strategies can compensate for in-hand pose uncertainties during mating, enabling reliable assembly even with high-clearance gripper jaws. This integrated approach significantly enhances automation potential in connector assembly tasks.

[22] Pick and place robots play a vital role in industrial automation by reducing manual effort and improving accuracy. Riyadi et al. (2017) proposed a robotic system integrating RFID-based object classification and STM32 microcontroller control for intelligent sorting. Unlike traditional color-based systems, their design used RFID tags for object identification, enabling more reliable and unique classification. The STM32VLDISCOVERY board controlled X, Y, and Z-axis movements and successfully placed objects based on tag data and sensor inputs. This research demonstrates an efficient, low-cost automation approach suitable for dynamic production environments.

[23] High-speed pick-and-place operations demand mechanisms with exceptional dynamic performance. COMPANY et al. (2004) introduced the Par4 parallel robot, an evolution of Delta, H4, and 14 architectures, designed specifically for very high-speed tasks. By replacing prismatic joints with revolute ones and optimizing actuator arrangement, Par4 achieves superior stiffness and symmetrical behavior. Through kinematic analysis and Adept Motion-based optimization, it reached 13 G acceleration with a cycle time of 0.28 s. This work addresses the limitations of earlier SCARA-type parallel manipulators and offers a promising solution for industrial high-speed applications.

[24] In the context of Industry 4.0, pick-and-place automation plays a crucial role in enhancing warehouse efficiency. Canales et al. (2023) developed a low-cost Cartesian robot integrated with a PLC and machine vision to perform autonomous pick-and-place operations. Using Siemens PLC, NEMA 23 motors, and a suction-based end effector, the system demonstrated accurate object handling. A convolutional neural network trained via Roboflow enabled object recognition, while integration with a Warehouse Management System improved tracking and planning. This approach proves that robust, scalable, and low-cost solutions can be effectively implemented in logistics environments.

[25] Simulation-based tuning of robot motion is critical for improving pick-and-place (P&P) reliability with vacuum grippers. Karako et al. (2017) proposed a practical simulation method combining a viscoelastic dynamics model and grasp stability estimation. Unlike prior approaches limited to specific workpieces or grippers, their method is adaptable to diverse configurations by integrating simple model structures with experimental identification. Validated through trials with various suction cups and loads, the approach accurately predicts object acceleration and grasp stability. This makes it a practical tool for optimizing P&P robot design and minimizing real-world trial-and-error effort.

[26] Tactile sensing in soft robotics enables delicate object handling with precision. Nichols Cook et al. (2020) developed a 3D-printed soft tri-gripper integrated with a capacitive tactile sensor array embedded within thermoplastic polyurethane (TPU) phalanges. The design ensures low cross-sensor coupling and robust integration using stretchable copper electrodes. The gripper achieved a maximum sensitivity of 2.87%/kPa and was tested in a vision-guided fruit pick-and-drop application. This integration of visio-tactile feedback enhances closed-loop control for safe grasping, showing promise for use in agriculture and industrial automation.

[27] Yi et al. (2002) proposed a novel parallel-type gripper mechanism featuring a foldable parallelogramic platform, allowing it to grasp irregularly shaped or large objects and serve as a micro-positioning device. The study presented kinematic analysis, optimization, and a unique pneumatic actuation system with a miniaturized proportional valve enabling indirect force control. The design improves stiffness, workspace coverage, and force generation through base actuation. Experimental results confirmed effective motion tracking and grasping force estimation. This mechanism offers enhanced flexibility and control compared to traditional serial grippers, making it suitable for advanced robotic applications

[28] Gebauer et al. (2024) proposed a robot-based method for sensitive mating of electrical connectors using automatically designed gripper jaws with parameterizable clearance. This method addresses challenges posed by non-planar grasping surfaces and geometric uncertainties in plug positioning. The study builds on earlier work in gripper design automation and introduces sensitive joining strategies to compensate for in-hand pose deviations.

Experiments with three high-voltage connectors demonstrated that gripper jaws with higher clearance improved grasp success, while sensitive joining maintained high mating accuracy. This approach enhances automation of complex connector assembly tasks in industrial applications.

[29] Navas et al. [1] review the role of soft grippers in automating crop harvesting, focusing on their adaptability, safety, and potential for handling delicate fruits in unstructured environments. The study highlights key factors in soft gripper design, including material properties, actuation methods, and control strategies. Silicone elastomers are favored for their compliance and ease of fabrication. Fluidic elastomer actuators (FEAs) and tendon-driven systems show promise in agricultural use. Challenges include standardizing performance evaluation, energy efficiency, and economic feasibility. The review positions soft grippers as vital tools in advancing Agriculture 4.0.

[30] This article provides a comprehensive overview of robotic grippers, discussing various designs ranging from surgical tool effectors to dexterous hands. It emphasizes the importance of considering design, form, and function in robotic grippers as systems become more autonomous.

[31] This paper focuses on the design of a hydraulic-driven robotic gripper, detailing the transmission structure, kinematics, and statics. It proposes a linkage mechanism to enhance the gripper's performance in various applications.

[32] This research presents the design and development of an underactuated soft robotic gripper tailored for space applications. It analyzes current gripper types, reviews promising designs, and delves into critical technologies relevant to space environments.

[33] This paper introduces a novel robotic gripper utilizing a thermoplastic elastomer belt. The design allows for adaptive gripping through a flexible contact surface, making it suitable for handling objects of varying shapes and textures.

[34] To address energy inefficiencies in SCARA robots, Goya et al. (2012) proposed an innovative resonance-based control strategy using adaptive elastic devices at each joint. This method enables the robot to convert kinetic energy into potential energy via harmonic oscillations, significantly reducing energy consumption during pick-and-place operations. Experimental results with a vacuum pad-equipped SCARA robot demonstrated over 72% energy savings when moving chocolate plates. Unlike previous fixed-point methods, this system dynamically adjusts start/end positions while preserving efficiency. The work establishes a practical framework for energy-efficient industrial automation.

[35] Fiestas and Prado (2018) addressed the need for precise trajectory control in agricultural Cartesian robots by modeling and simulating the Farmbot system. They developed a kinematic model incorporating inverse kinematics, Jacobian matrices, and a Cubic Spline interpolator to ensure smooth, point-to-point (PTP) motion. A 3D virtual simulation environment in MATLAB/Simulink validated the model's effectiveness. This work enhances motion synchronization and reduces errors in positioning, making it suitable for tasks such as fruit handling and seedling transplanting, where precision and flexibility are vital for smart farming systems.

[36] Robotics has evolved from simple autonomous machines to sophisticated systems mimicking human actions. Modern industrial robots, especially pick and place types, play a vital role in automation due to their accuracy, consistency, and efficiency. As highlighted by Ugale et al. [1], these robots utilize microcontroller-based systems integrated with infrared sensors to detect, pick, and place objects efficiently. The incorporation of degrees of freedom (DOF) and diverse configurations enables flexible operations across industries. Robotics not only reduces human labor in repetitive and hazardous tasks but also enhances productivity and cost-effectiveness in manufacturing environments [1].

[37] Pick and place robotic arms are essential in automation due to their precision, adaptability, and ease of integration in various applications. Dr. T. Sunil Kumar et al. [1] designed a robotic arm powered by servo motors and fabricated using aluminum for its strength and lightweight properties. The arm was modeled in CATIA and programmed in C++, with torque and power calculations used to select suitable actuators. Their work emphasizes the educational value of such systems and highlights the importance of accurate kinematic analysis and material selection in robotic arm design and performance optimization.

[38] Peng et al. [1] developed a soft robotic gripper with rigid supports and variable-hardness silicone to enhance adaptive grasping. The gripper combines Ecoflex-0030 and Ecoflex-0050 materials to improve bending performance and contact area. Stainless steel supports were added externally to amplify lifting force by 150 ± 20% compared to unsupported versions, enabling the gripper to lift up to 5 kg under only 30 kPa. Finite element simulations and experiments confirmed improved performance in terms of adaptability, strength, and energy efficiency. Applications span robotics in logistics, agriculture, and healthcare.

[39] Hao and Visell [1] explore alternatives to anthropomorphic robotic hands, proposing efficient soft grippers that use enveloping, adhesion, wrapping, and suction to simplify grasping tasks. These non-anthropomorphic designs reduce the need for complex sensing, control, and actuation while maintaining the ability to handle diverse objects. Inspired by biological systems like gecko feet and chameleon tongues, such grippers demonstrate adaptability, low energy consumption, and reduced mechanical complexity. The authors highlight the potential for these systems in logistics, service robotics, and manufacturing, while also discussing challenges like scalability, speed, and precision.

[40] Automation using pick and place robotic arms has become vital for efficient warehouse management. These robots, often designed with 5 degrees of freedom (DOF), provide precise, fast, and reliable handling of products. Sobhan and Shaikat [1] implemented a robotic arm system integrated with Arduino control, GSM-based mobile applications, and PID tuning for enhanced performance. Their system demonstrated effective object detection, placement, and remote operability, aiming to reduce human error and increase operational efficiency in smart warehouses. The combination of mechanical design, kinematic analysis, and mobile control highlights significant advancement in warehouse automation technologies.

[41] In this paper, we make a Mobile Gantry Robot. As the gantry robot having the most stable configuration used for various application like welding, pick and place, etc. Here, we are moving the 3-axis complete Gantry Structure by using the wheel sand dc motor and controlling the complete Mobile Gantry Robot with the help of web-server which give instructions to the Microcontroller and then the micro-controller give instruction to the actuators (motor).

3. METHODOLGY

3.1 Design Thinking

Design Thinking is a human-centered, iterative problem-solving approach that focuses on understanding user needs, challenging assumptions, and creating innovative solutions. It is widely used in engineering, business, and product development to enhance creativity and ensure user-centric designs. The below fig 3 represents the design thinking.

The process involves five key stages: Empathize, Define, Ideate, Prototype, and Test. By prioritizing experimentation, collaboration, and user feedback, Design Thinking helps develop effective and scalable solutions.

1. Empathize – Understand users' needs, challenges, and emotions through observation, interviews, and research to create human-centered solutions.
2. Define – Clearly articulate the problem by analyzing insights from the empathize stage, ensuring a focused and meaningful problem statement.
3. Ideate – Brainstorm multiple creative solutions without limitations, encouraging innovation and exploring different perspectives to address the defined problem effectively.
4. Prototype – Develop low-cost, simplified models of potential solutions to visualize concepts, gather feedback, and refine ideas before full-scale implementation.
5. Test – Evaluate prototypes with users, collect insights, and iteratively improve designs based on real-world feedback for optimal problem-solving effectiveness.

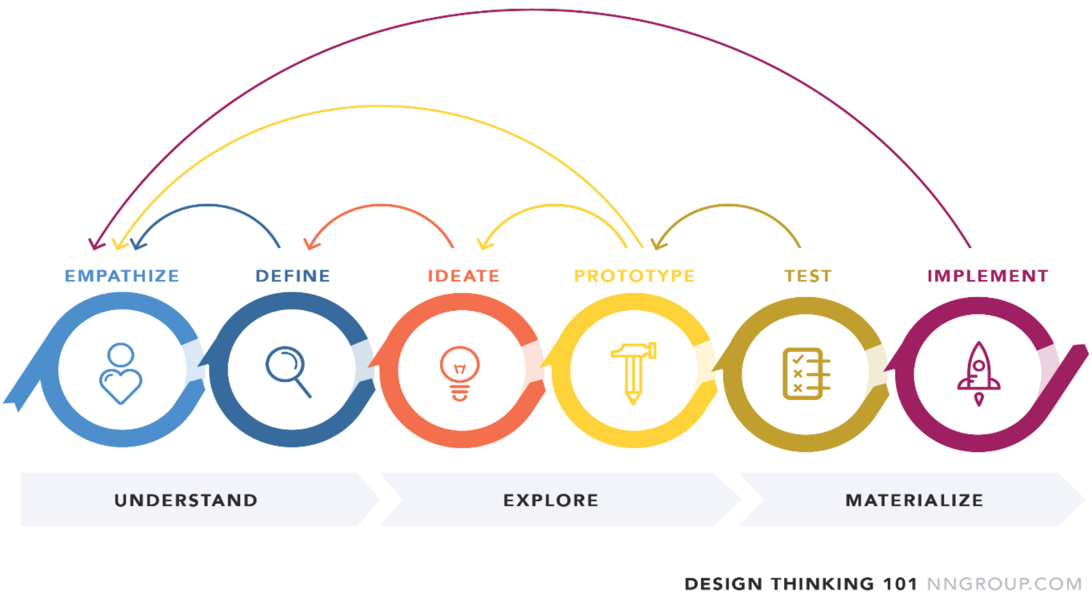

Fig3.1-Design thinking

3.2 Stakeholder Map

The below fig 3.2 identifies the stakeholder map which includes primary, secondary and tertiary stakeholders

Fig 3.2- Stakeholder Map

Primary Stakeholders:

1. Worker 1 – Currently responsible for manually picking and placing IB plates
2. Worker 2 – As one of the primary workers handling IB plates by hand, and has hands-on experience with the process
3. Worker 3 – Another person who is also engaged in manually transferring plates

Secondary Stakeholders

1. Prakash – Manager who is involved in system support, maintenance, or indirect operations that affect the functioning.
2. Supervisor – Instructor who is engaged in the automation implementation, troubleshooting, or process supervision.

Tertiary Stakeholders

1. Amogh Bhuti – A teammate involved in project planning, documentation, and coordination, ensuring smooth execution and collaboration among all stakeholders.
2. Dr. Sachin Karadgi – Mentor or guide, providing expert guidance on the technical and research aspects of oiling station automation.

3.3 Stakeholder Persona

The below fig 3.3.1 represents the primary stakeholder persona 1 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

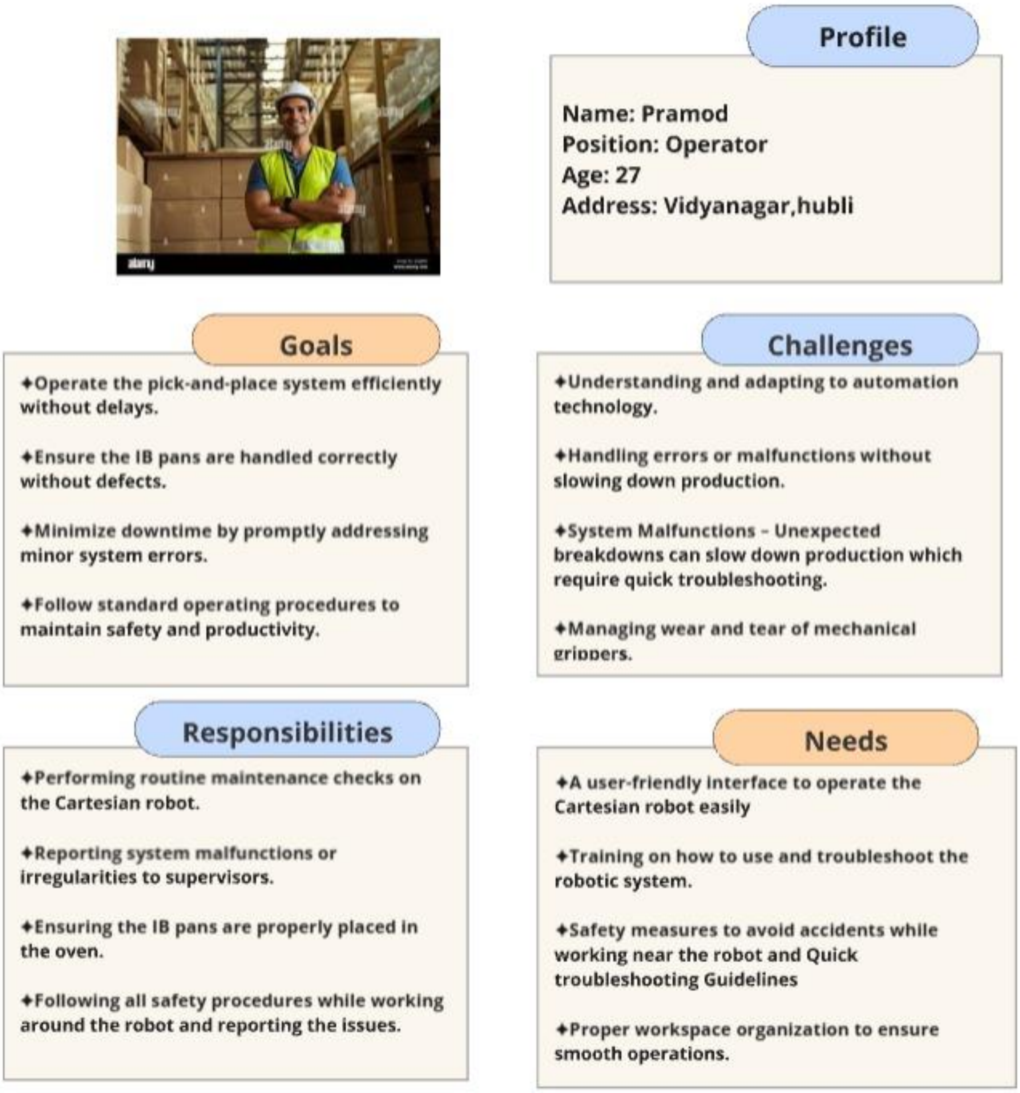

Fig 3.3.1: Primary Stakeholder Persona 1

The below fig 3.3.2 represents the primary stakeholder persona 2 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

Profile

Name: Ganesh
Position: Worker - 2
Age:28
Address: Gokul Hubli.

Goals

✦Ensure no scratched or misaligned IB pans enter the oven.

✦Maintain high-quality standards throughout the process.

✦Minimize rework and rejection rates due to improper handling.

Challenges

✦Detecting subtle defects that automation might miss.

✦Working quickly without compromising accuracy.

✦Coordinating with the other operator for process corrections.

Responsibilities

✦Inspecting IB pans after pick-and-place operation.

✦Reporting defects to the production manager.

✦Providing feedback on system accuracy and improvement areas.

✦Ensuring the quality standards are maintained before oven processing.

Needs

✦A consistent and precise robotic system to reduce defects.

✦Clear inspection guidelines for checking IB pans.

✦Tools for quick defect identification.

✦Safety measures to avoid accidents.

Fig 3.3.2:Primary Stakeholder Persona 2

The below fig 3.3.3 represents the primary stakeholder persona 3 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

Profile

Name: Ramesh
Position: Worker - 3
Age: 31
Address: Vidynagar,hubli.

Goals

✦Minimize downtime by quickly resolving mechanical or software issues.

✦Keep maintenance costs low by following preventive maintenance schedules.

✦Follow standard operating procedures to maintain safety and productivity.

Challenges

✦Diagnosing issues quickly to prevent production delays.

✦Managing wear and tear of mechanical grippers.

✦Keeping up with software updates and system optimizations.

Responsibilities

✦Operating and monitoring the robotic pick-and-place system.

✦Troubleshooting and repairing mechanical or electrical faults.

✦Ensuring the gripper mechanism is properly aligned and functional.

✦Keeping records of repairs and recommending system improvements.

Needs

✦A user-friendly interface to operate the Cartesian robot easily

✦Training on how to use and troubleshoot the robotic system.

✦Safety measures to avoid accidents while working near the robot.

Fig 3.3.3:Primary Stakeholder Persona 3

The below fig 3.3.4 represents the secondary stakeholder persona 1 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

Fig 3.3.4: Secondary Stakeholder Persona 1

The below fig 3.3.5 represents the secondary stakeholder persona 2 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

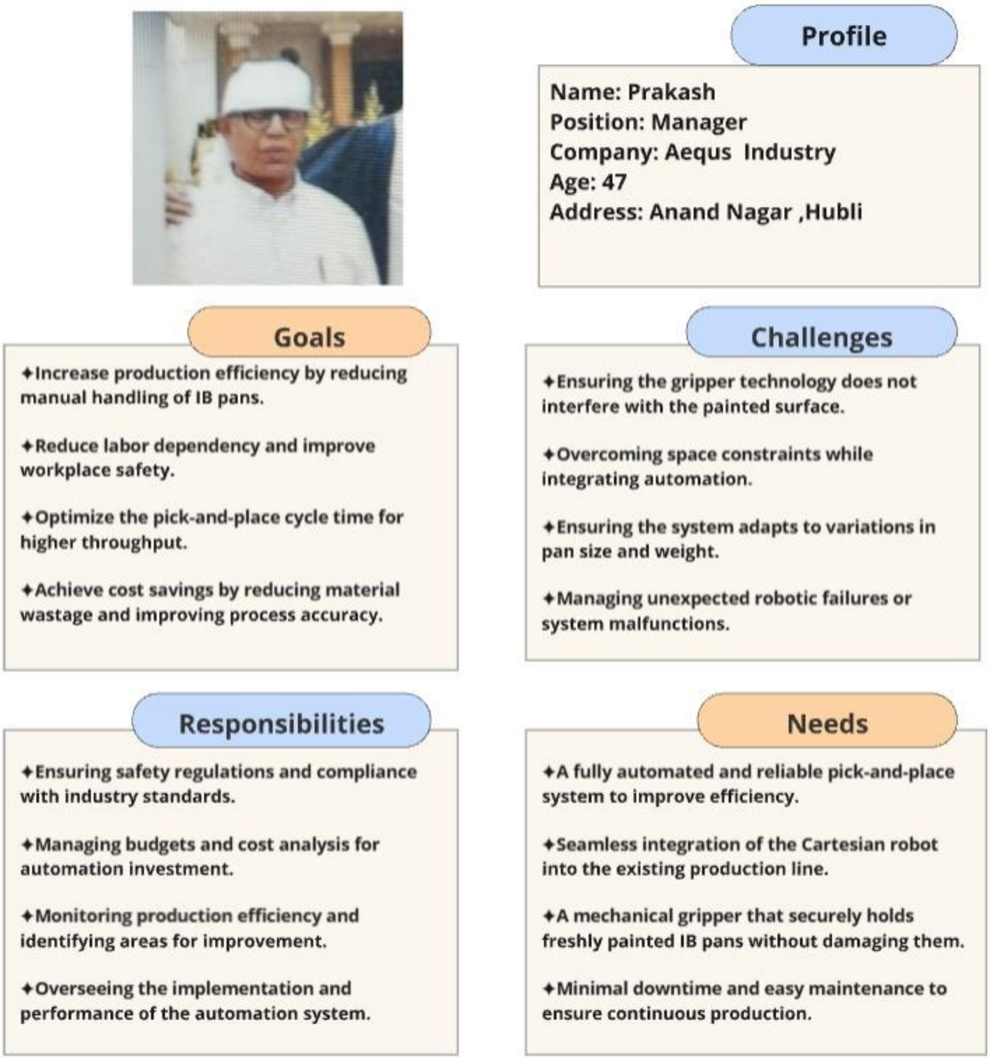

Fig 3.3.5: Secondary Stakeholder Persona 2

The below fig 3.3.6 represents the tertiary stakeholder persona 1 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

Fig 3.3.6: Tertiary Stakeholder Persona 1

The below fig 3.3.7 represents the tertiary stakeholder persona 2 with respective their bio data, responsibility, needs, goals and challenges with respective to their life for automation system.

Fig 3.3.7: Tertiary Stakeholder Persona 2

3.4 Empathy Map

The below fig 3.4.1 shows the Empathy Map for the Primary Stakeholder highlights their need for efficiency, accuracy, and reduced strain. Workers handling repetitive placement tasks face fatigue, focus loss, and workflow inconsistency, risking part damage and reduced accuracy. A Cartesian robot with a 3-finger gripper can automate these tasks, ensuring consistency, minimizing errors, and enabling operators to focus on higher-value work.

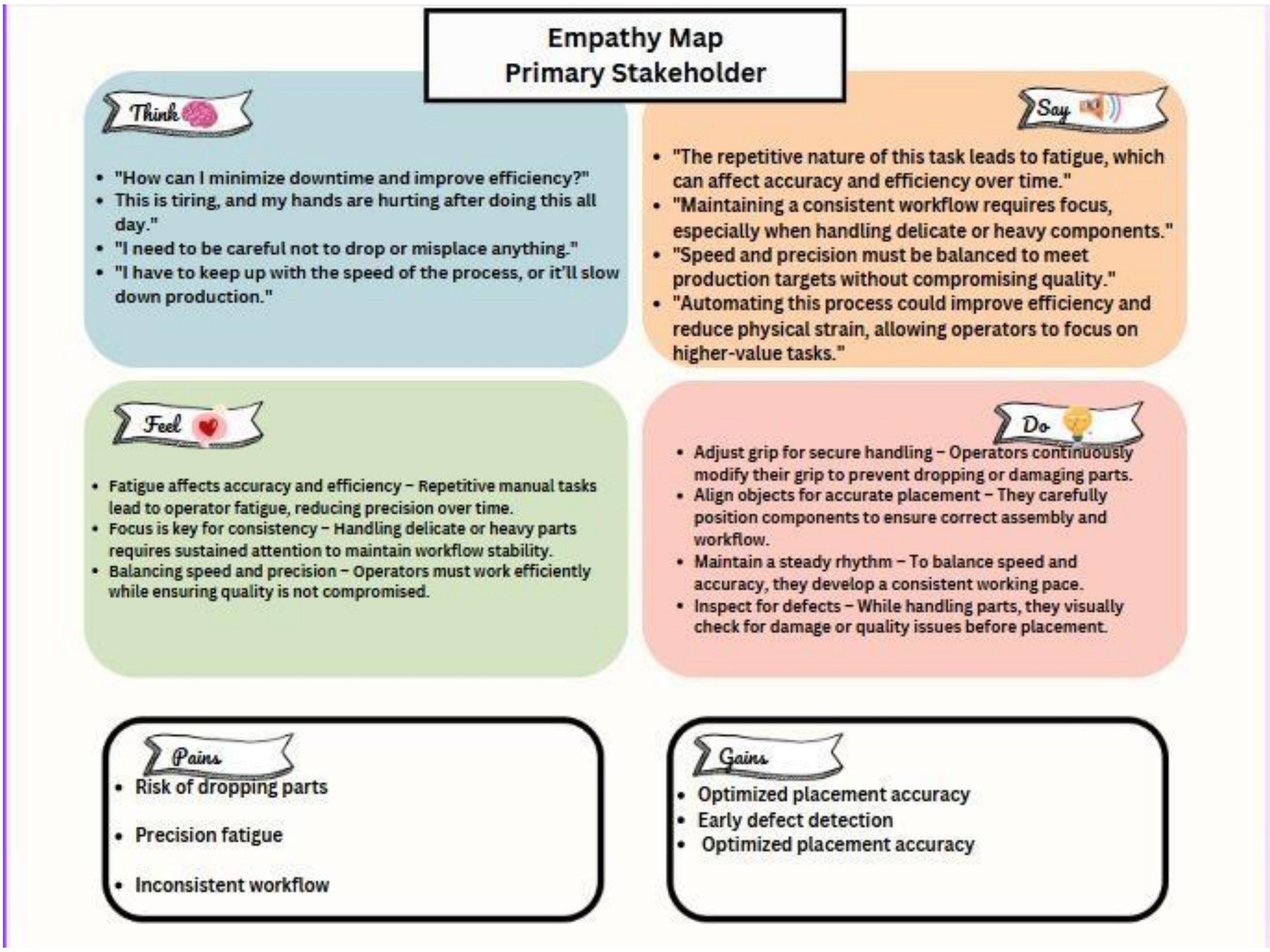

Fig 3.4.1: Primary Stakeholder Empathy Map

The below fig 3.4.2 shows the Empathy Map for the Secondary Stakeholder focusing on supervisors, quality inspectors, and production engineers who manage system performance and safety. Their primary needs revolve around system reliability, safety compliance, and minimal downtime. These stakeholders are concerned with maintaining high output quality, minimizing rework, and ensuring efficient cycle times. Challenges include gripper-induced surface damage, frequent manual interventions due to breakdowns, and limited workspace flexibility.

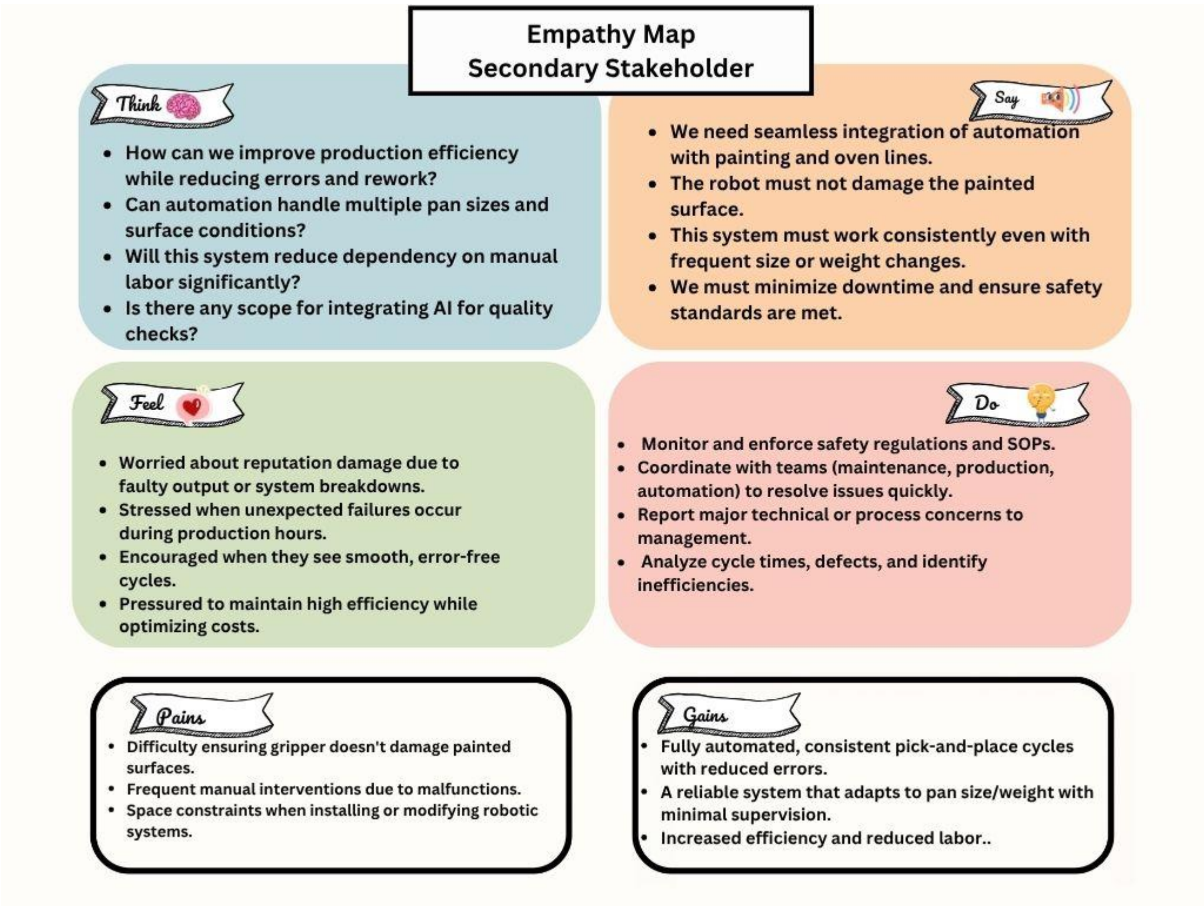

Fig 3.4.2: Secondary Stakeholder Empathy Map

The Below fig 3.4.3 shows the Empathy Map for the Tertiary Stakeholder highlights their role in ensuring student safety and bridging theory with practice. Educators aim to deliver industry-relevant robotics training but face challenges in time management, safety enforcement, and error handling. The Cartesian robot project aids hands-on learning, encourages simulation-based training, and builds problem-solving, teamwork, and practical skills aligned with real-world industry expectations.

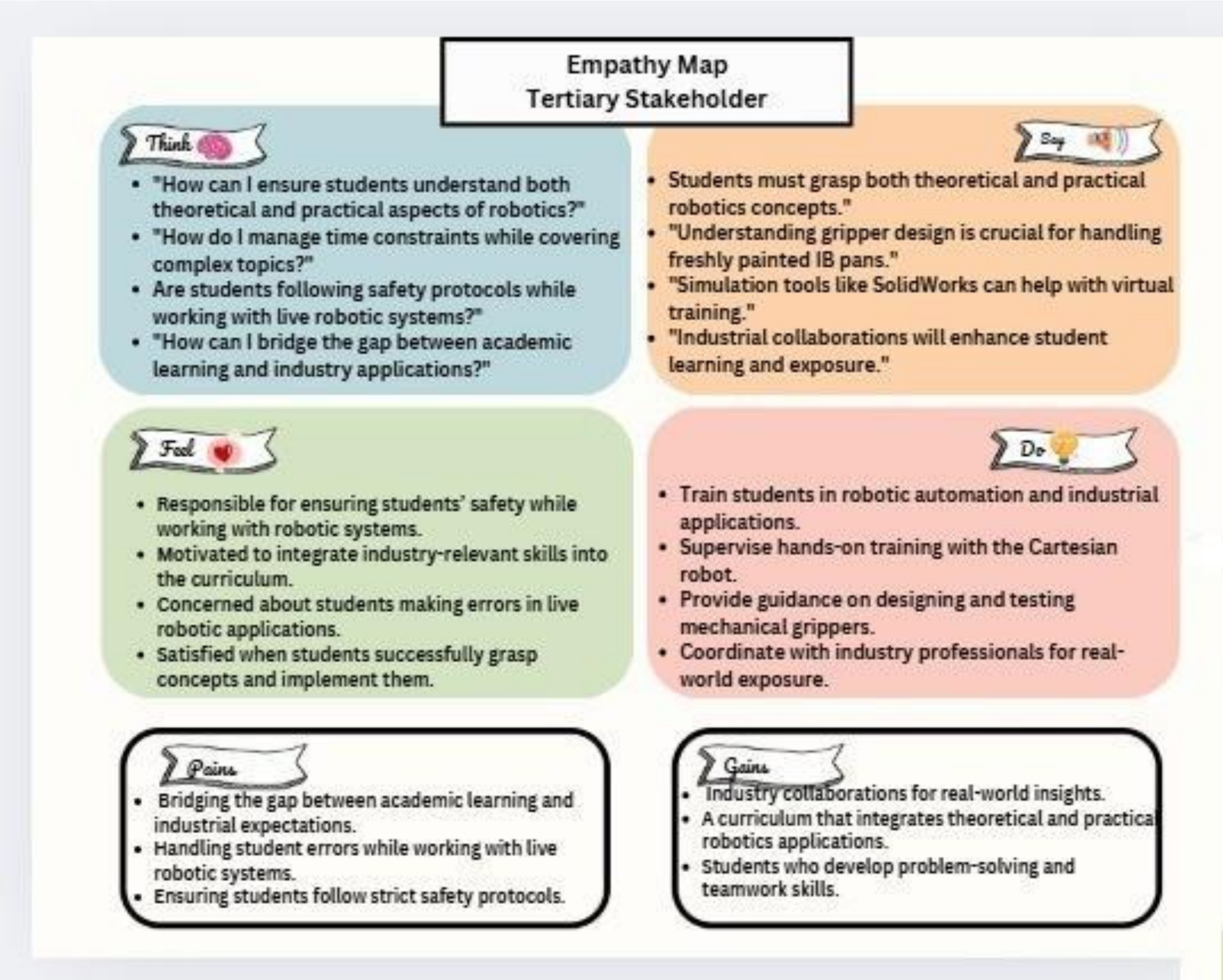

Fig 3.4.3: Tertiary Stakeholder Empathy Map

3.5 User Needs

The below table 4.0 represents the User needs for automation system.

Table No 3.5 User Needs

Serial Number	User Need
1.	The operator needs an automated pick-and-place system to reduce manual handling of IB pans.
2.	The operator needs a reliable gripping mechanism to securely hold the IB pan without slipping.
3.	The operator needs a non-contaminating gripper to ensure that the freshly painted pan surface is not damaged.
4.	The operator needs an intuitive control system for easy operation and monitoring.
5.	The operator needs a visual indicator or alarm in case of gripping failure or misalignment.
6.	The operator needs real-time feedback on system status to ensure smooth operation.
7.	The operator needs minimal physical effort in system operation to reduce fatigue.
8.	The engineer needs a Cartesian robot with precise motion control to accurately place IB pans in the oven.
9.	The engineer needs a mechanical gripper that adapts to different IB pan sizes and shapes.
10.	The engineer needs a sensor-based detection system to identify the correct position of the IB pan before picking.
11.	The engineer needs quick-change gripper attachments for easy maintenance and adaptability.
12.	The engineer needs a fail-safe mechanism to prevent dropped or misaligned pans.
13.	The engineer needs seamless integration of the robot with the existing production line.
14.	The engineer needs modular components to simplify repairs and upgrades.
15.	The manager needs minimal downtime to ensure continuous production flow.

16.	The manager needs an efficient system to increase productivity and reduce cycle time.
17.	The manager needs reduced wastage by preventing damage to freshly painted IB pans.
18.	The manager needs automation to improve consistency and minimize defects in pan placement.
19.	The manager needs compliance with safety regulations to meet industry standards.
20.	The manager needs an energy-efficient robotic system to reduce operational costs.
21.	The system needs minimal power consumption to optimize energy use.
22.	The system needs a low-noise operation to maintain a comfortable work environment.
23.	The manager needs a compact system that fits within the existing production space
24.	The system needs to have safety interlocks to prevent accidents during robot operation.
25.	The system needs emergency stop functionality for quick shutdown in case of malfunctions.
26.	The system needs protective barriers or sensors to ensure worker safety.
27.	The system needs easy-to-clean surfaces to prevent contamination and dust accumulation.
28.	The system needs predictive maintenance alerts to prevent unexpected failures.
29.	The system needs vibration and shock resistance to maintain stability during pick-and-place operations.
30.	The system needs a secure grip mechanism to handle variations in pan weight.
31.	The system needs to comply with industry regulations for handling painted components.
32.	The system needs to minimize air disturbances that might affect the drying of painted pans.

3.6 Requirement list

The Bellow table 4.1 represents the Requirements list for automation system.

Table No 4.1 Requirement list

Serial number	Requirements
1.	The Cartesian robot must be designed to operate efficiently within a compact work area.
2.	The Cartesian robot must move along the X and Z axes with precise motion control (stepper/servo).
3.	It must have a 3-finger linear gripper capable of picking IB plates securely and gently.
4.	It must classify plates as good or bad using vision inspection or sensor feedback.
5.	It must sort and place good plates in one location and bad plates in another.
6.	It must work reliably in a compact, space-constrained production environment.
7.	It must include a reliable power supply (e.g., 24V DC) to energize all subsystems.
8.	It must include an emergency stop button at accessible locations for safety.
9.	It should support plate orientation detection using vision or dual sensors before picking.
10.	The gripper should have adjustable gripping force to handle plates of different thickness/weight.
11.	The robot should detect and alert for grip failure or misalignment using force or position sensors.
12.	The robot should include a feedback system (encoders or sensors) to correct position errors.
13.	The robot should support quick gripper replacement or modular tooling for different plate types.
14.	The system should support a user-friendly HMI for manual jog, diagnostics, and parameter updates.
15.	The robot should operate with optimized motion planning to reduce cycle time.
16.	It could support predictive maintenance by logging actuator usage or vibration data.
17.	It should have a vision system for enhanced accuracy

Serial number	Requirements
18.	It should have a feedback system for real-time error correction
19.	It should have a user-friendly interface for easy control and monitoring
20.	It should have an emergency stop mechanism for safety
21.	It should have an energy-efficient design to optimize power consumption
22.	It could have AI-based object recognition for adaptive picking.
23.	It could have IoT integration for remote monitoring and control
24.	It could have a dual-arm mechanism for increased efficiency.
25.	It could have predictive maintenance using ML algorithms.
26.	It could have modular components for easy upgrades
27.	It could have collaborative robot features for human-robot interaction.
28.	It could have a wireless control system for flexibility in operation.
29.	It won’t have manual intervention in the picking process.
30.	It won’t have dependency on non-industrial-grade components.
31.	It won’t have excessive wiring that hampers mobility.
32.	It won’t have non-standard communication protocols.
33.	It could include collaborative safety features like light curtains or force-limited movement.
34.	It could operate with dual grippers or parallel arms for higher throughput (future upgrade).

3.7 Prioritizing Requirements

The below Fig 3.7 MoSCoW Technology represents prioritized requirements for an automation system under Must Have, Should Have, Could Have, and Won't Have categories.

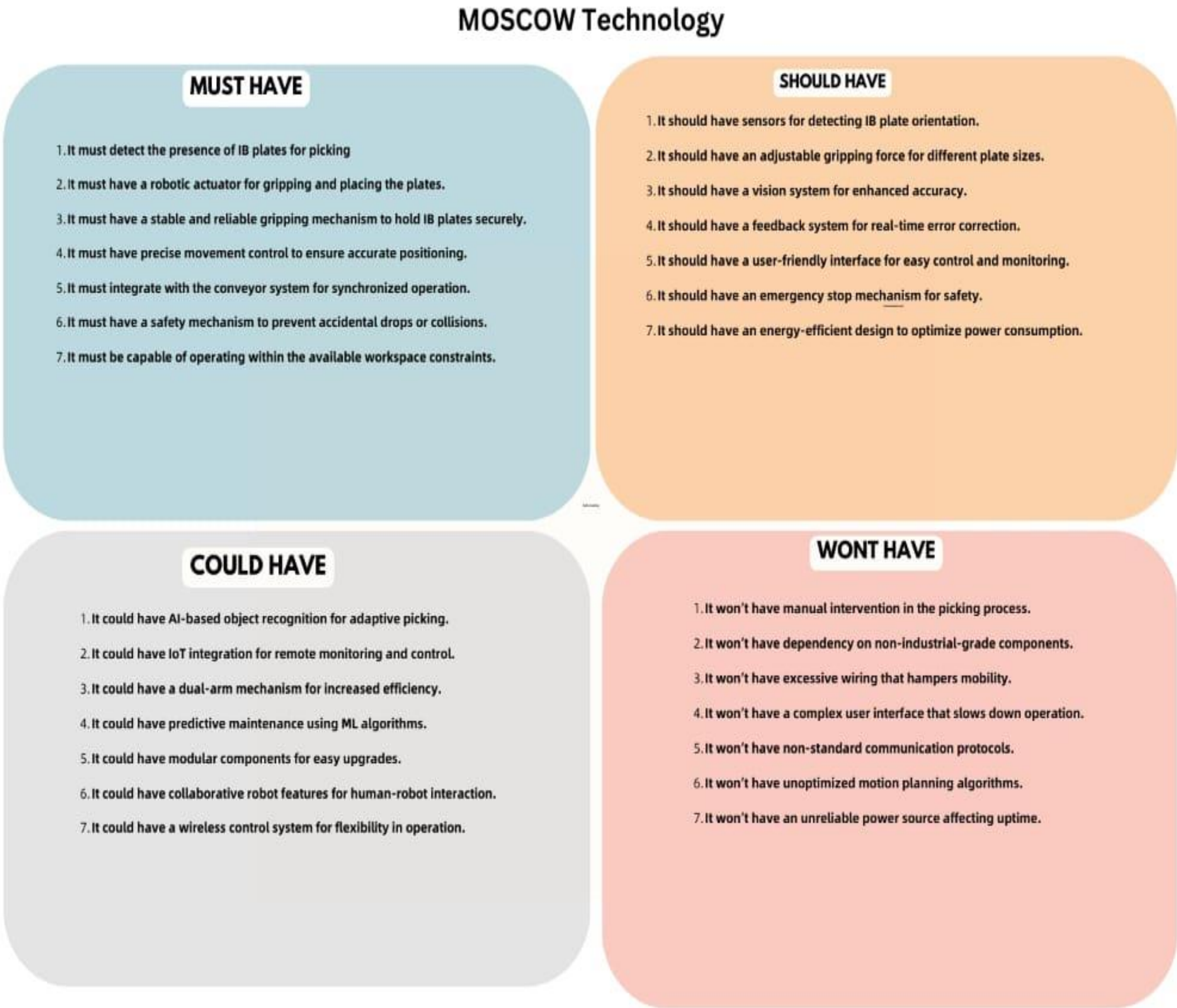

Fig 3.7: MoSCoW Technology

3.8 Morphological Chart

The below Fig 3.8: Morphological Chart presents various solution alternatives for each sub-function of the system, including motion, sensing, control, construction, movement, and gripping.

→ MORPHOLOGICAL CHART

SUB FUNCTIONS	MEAN 1	MEAN 2	MEAN 3	MEAN 4	MEAN 5
MOTION	Stepper motor	Servo motor	DC motor	Pneumatic actuator	-
SENSING	proximity sensor	IR sensor	Ultrasonic sensor	Vision Sensor	-
CONTROLLING	Arduino	STM32	PLC	ESP32	Raspberry Pi
CONSTRUCTING	Aluminum extrusion	Mild steel	Acrylic laser-cut sheets	3D-printed PLA/ABS parts	Laser-cut plywood housing
MOVE IN X-Z AXIS	Lead screw	Timing belt + pulleys	Rack and pinion	Linear actuators	Stepper + rail (openbuild)
GRIPPING	2-jaw mechanical gripper	3-jaw mechanical gripper	Magnetic finger gripper	pneumatic gripper	Vacuum gripper

Fig 3.8: Morphological Chart

3.8.1 Conceptual Design

1) Below fig3.8.1 illustrates a top-down view of the 2-axis gantry robot system. The rails and structural supports guide the linear motion, and the mounted gripper enables material handling over a work area, suitable for industrial automation applications.

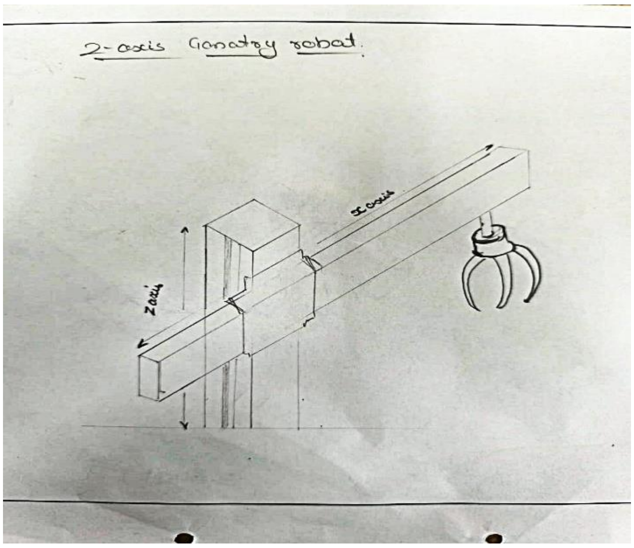

Fig 3.8.1: 2- Axis gantry robot

2) Below fig3.8.2 shows a 3-axis Cartesian robot with labelled X and Z axes. The gripper moves horizontally along X and vertically along Z, enabling pick-and-place operations for lightweight components with precise linear movement.

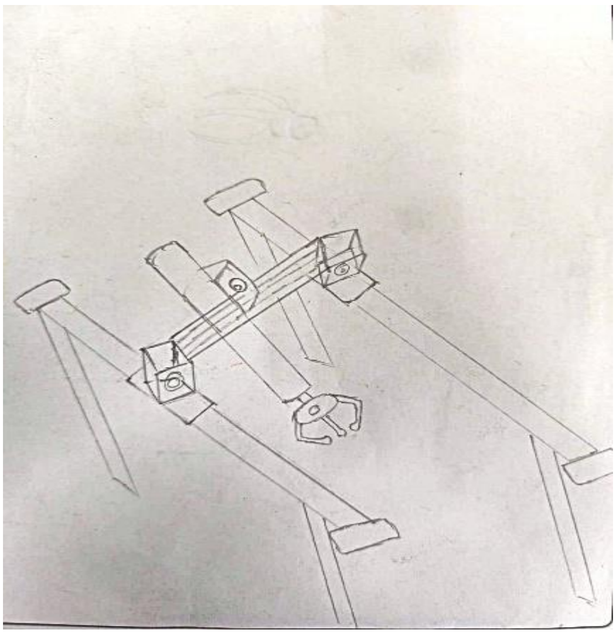

Fig 3.8.2: 3- Axis Cartesian robot

3) Below fig3.8.3 displays a refined design of the 3-finger pneumatic gripper in an isometric view. The structure emphasizes mechanical linkages and central actuation for synchronized finger motion, improving reliability and uniform gripping force during pick-and-place tasks.

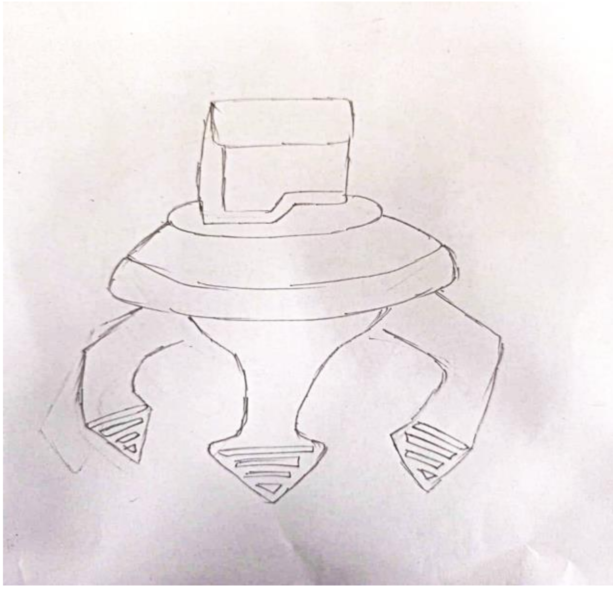

Fig 3.8.3: 3- Finger pneumatic gripper

4) Below fig3.8.4 presents a close-up sketch of a 3-finger mechanical gripper. The symmetrical finger design allows stable gripping of cylindrical or flat components like IB plates. The gripper likely integrates with servo or pneumatic actuation.

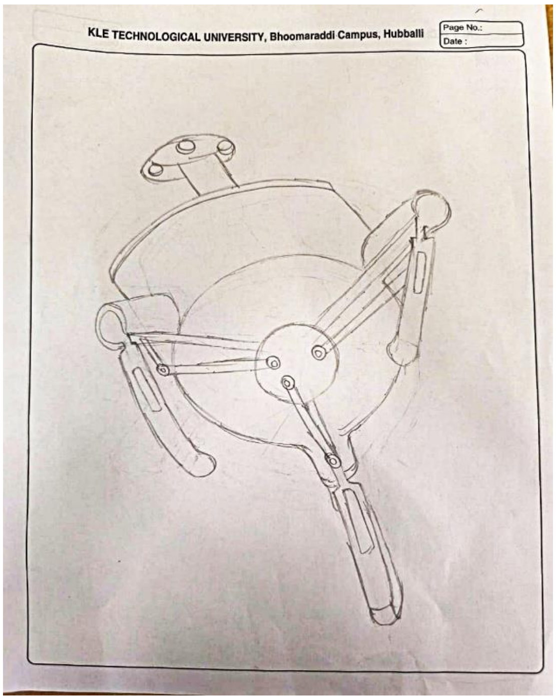

Fig 3.8.4: 3- Finger pneumatic gripper

3.9 Concept Screening

The below Fig 3.9: Concept Screening evaluates robotic configurations against key criteria, ranking Cartesian as the most viable concept for continuation.

Concept Screening

Criteria	Base line	Cartesian	SCARA	Delta	Articulated Arm
Payload Capacity	0	+	+	+	+
Speed	0	0	+	+	+
Precision	0	+	+	0	-
Reach / Working Volume	0	0	0	-	+
Cost	0	+	0	-	-
Repeatability	0	+	+	0	-
Ease of Programming	0	0	+	-	-
Ease of Integration	0	+	0	-	-
Maintenance Requirements	0	+	0	-	-
Structural Rigidity	0	+	0	-	-
Energy Consumption	0	0	0	-	-
Flexibility	0	0	+	-	+
Safety	0	0	0	0	-
Simplicity	0	+	0	-	-
Total	-	4	1	-8	-7
Rank	-	1	2	4	3
Continue	-	YES	NO	NO	NO

Fig 3.9: Concept Screening

3.10 Concept Scoring

The below Fig 3.9: Concept Scoring quantitatively compares robotic concepts, confirming Cartesian as the top choice based on cumulative scores across all evaluation criteria

Concept Scoring

Criteria	Base line	Cartesian	SCARA	Delta	Articulated Arm
Payload Capacity	5	4	3	2	4
Speed	5	3	4	5	4
Precision	5	5	4	3	2
Reach / Working Volume	5	3	4	3	5
Cost	5	5	3	2	2
Repeatability	5	5	4	3	2
Ease of Programming	5	4	4	3	2
Ease of Integration	5	5	4	3	2
Maintenance Requirements	5	5	4	3	2
Structural Rigidity	5	5	4	3	2
Energy Consumption	5	4	4	3	2
Flexibility	5	3	4	2	5
Safety	5	4	4	3	3
Simplicity	5	5	4	3	2
Total	70	65	56	42	39
Rank	-	1	2	4	3
Continue	-	YES	NO	NO	NO

Fig3.9: Concept Scoring

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3.11 System Planning and Problem Analysis

The project began by evaluating the limitations of manual IB plate handling, such as inconsistent placement, human error, and low throughput. These observations highlighted the need for an automated solution that ensures reliable and consistent plate transfer. A 2-axis Cartesian robot was chosen to achieve linear motion in horizontal (X) and vertical (Z) directions, minimizing complexity while maximizing efficiency.

3.12 Mechanical Design

The robot's frame was constructed using aluminium extrusion for lightweight strength, structural stability, and ease of modular adjustments. Linear rails and timing belts were used to facilitate smooth and precise movement along the X and Z axes. The 3-finger gripper was selected for better grip stability and adaptability to handle plates with varying surface conditions, ensuring secure pick-and-place without slippage.

3.13 Component Selection

Key components were selected for performance, payload capacity, and cost-effectiveness:

- Stepper Motors (NEMA 23) – Provided high torque and precise step resolution, suitable for lifting up to 600 g payloads.
- Timing Belts and Pulleys – Enabled smooth and efficient motion transmission for both axes.
- Linear Rails – Ensured accurate, guided linear motion under the robot's full payload.
- 3-Finger Gripper – Offered a stable grip on IB plates, accommodating small variations in size and surface.
- Motor Drivers and Power Supply – Regulated and powered the motors for reliable operation.

3.14 Control System Development

The control logic was developed using either STM32 Nucleo-F401RE programmed via STM32CubeIDE or Arduino using the Arduino IDE. The microcontroller sends precise step commands to the stepper motor drivers for axis control and manages the servo-based gripper. The system is programmed with proper sequencing, home position logic, and error recovery functions. Safety interlocks and sensor feedback were integrated to ensure reliable cycle completion and fault detection.

3.15 Bill of Materials

The below fig 3.15 BOM represents the bill of material of our automation system.

Sl. NO.	Components	Specification	QTY	Estimated Cost	Reference
1.	Aluminum Profile Frame	1900X80X30mm	2	9600rs	https://in.misumi-ec.com/vona2/detail/110310647729/?HissuCode=LCF8-4080-4000&aid=otid_04012024_01&utm_source=google&utm_medium=ads&utm_campaign=P_Max_Economy_Series_Sales_South_West&utm_id=22193436151&gad_source=1&gad_campaignid=22189649669&gbraid=0AAAAAC-g7457bpLgQb47d8-RzWuYJjv3g&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rgqrzW3NnrP0pQzvP_IfoSx1F4TXrEPVX9k4BhdhMhs1zm_LWrW6iBoCwlYQAvD_BwE
2.	Linear Rails	1700X15X15mm	2	8400rs	https://robu.in/product/mgn7h-linear-guide-rail-0-5m-2/?gad_source=1&gad_campaignid=17427803012&gbraid=0AAAAADvLFWd90KfnfiWg7vcgr8jpseOi8&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rpREotApcK-4Wx_0CxHy85z-Gbt3hka_K68nDaY3_OpB5pdrv97mNxoCk9YQAvD_BwE#tab-specification
3.	Carriage Blocks	60X45X20mm	2	3584rs	https://g.co/kgs/pW2SXAm
4.	pulleys	6mm Belt Width 60 teeth 8mm Bore Aluminium Timing Pulley	4	1200rs	https://robu.in/product/gt2-6mm-belt-width-60-teeth-8mm-bore-aluminium-timing-pulley/?gad_source=1&gad_campaignid=17427803012&gbraid=0AAAAADvLFWd90KfnfiWg7vcgr8jpseOi8&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rgaoXagvZrmL0WdqC3dbiOQZqN-DauXygyE24ZP43ABiIFouW217mBoCBoMQAvD_BwE
5.	lead srew	8mm(D) 250mm(L)	1	350rs	https://robu.in/product/150mm-trapezoidal-4-start-8mm-thread-2mm-pitch-lead-screw/?gad_source=1&gad_campaignid=17427803012&gbraid=0AAAAADvLFWd90KfnfiWg7vcgr8jpseOi8&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rn-Eg_NiUx5PPraEmsuu9IQ09pcGe05Q5eKQLdIw78NtYtW6sFiBzRoCKQUQAvD_BwE
6.	Smooth rod	8mm(D) 2200mm(L)	1	1000rs	https://robu.in/product/400-mm-long-chrome-plated-smooth-rod-diameter-8-mm/?gad_source=1&gad_campaignid=17427803012&gbraid=0AAAAADvLFWd90KfnfiWg7vcgr8jpseOi8&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rjg9SM7B1O9pPiqZaBT9k7u4NxwADzuQ3mMZu94UUdNWHa9lpe65dRoCauUQAvD_BwE
7.	Couplers	Aluminium 8 X 10mm Shaft Coupler	2	600rs	https://g.co/kgs/qE2EepT
8.	Flange	MS Flange	2	40	https://g.co/kgs/hSb6W18
9.	Limit Switch	TNI CONTROLS Basic Micro Limit Switch High Grade ABS Plastic Cast Body 15A/230V AC Micro Switch Dust, Water Proof & Oil Resistance Construction Pack of 1 Nos (Roller Pin Plunger - BSZ-15-RP)	3	900rs	https://www.amazon.in/TNI-CONTROLS-Plastic-Resistance-Construction/dp/B091GMW21L
10.	Stepper motor	Nema23 Closed Loop Integrated Stepper Motor Kit, 1450 RPM, Step Angle: 1.8 Degree	1	6000rs	https://www.indiamart.com/proddetail/nema23-closed-loop-integrated-stepper-motor-kit-2850542739230.html?utm_medium=prd_ads&utm_campaign=22473411111&keyword=&utm_source=google&gad_source=1&gad_campaignid=22473411111&gbraid=0AAAAAD-fhHp3KCe8ow0uXszjSK1979Uur&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rpUgOgGGeqUl6RyKnnuROzZgw6JP0fTE0xP4FVVubCAWkWtnGq1u0RoCVHoQAvD_BwE&gclsrc=aw.ds
11.	Servo motor	TowerPro MG996R High Torque Servo Motor - 360 Degree	1	250rs	https://quartzcomponents.com/products/mg996?variant=42799256436970&country=IN&currency=INR&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic?utm_source=google&utm_medium=FreeListings&gad_source=1&gad_campaignid=21214248935&gbraid=0AAAAACPPFdN3AfNCLMvyc6zmjJIx_Py9J&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rjsduHNPrQD7KIVQDszEuaoiJeMHCZaoPMJ4tpNhjcc9gTBv084dYxoC1wAQAvD_BwE
12.	Steppper motor	17HS4401 NEMA17 Stepper Motor - 40mm	1	600rs	https://robocraze.com/products/17hs4401-nema17-stepper-motor-40mm?variant=42490709246176&country=IN&currency=INR&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&campaignid=21596928874&adgroupid=&keyword=&device=c&gad_source=1&gad_campaignid=21596930350&gbraid=0AAAAADgHQvbLniDgR0vd1TWtOEdXkiesS&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rs_eO-mVxBunLwESlI4Ih_AYlO2LAT-3_Scvdw6lKgg8EXcqQ5qYwRoCNVwQAvD_BwE
13.	PLC	Omron Sysmac NX1P CPU with 24 Digital Transistor, NX1P2-9024DT1	1	57000rs	https://www.industrybuying.com/plc-accessories-omron-IND.PLC.625020272?utm_source=Google&utm_medium=PLA&utm_campaign=PLAM_Longtail_GSTPref_troas&gad_source=1&gad_campaignid=21488416206&gclid=CjwKCAjw6NrBBhB6EiwAvnT_rmp90oXvnJgSS6RzsOWhBmTeUmaENsTKmBulcJYeN31JGvNe_xAtwxoCOPwQAvD_BwE
				Total=₹91,524	

Fig 3.15: Bill of Material of Cartesian Robot

3.16 Detail Design

The below Fig 3.16 Cartesian robot with linear gripper illustrates a Cartesian robot integrated with a linear gripper and conveyor system for automated pick-and-place operations.

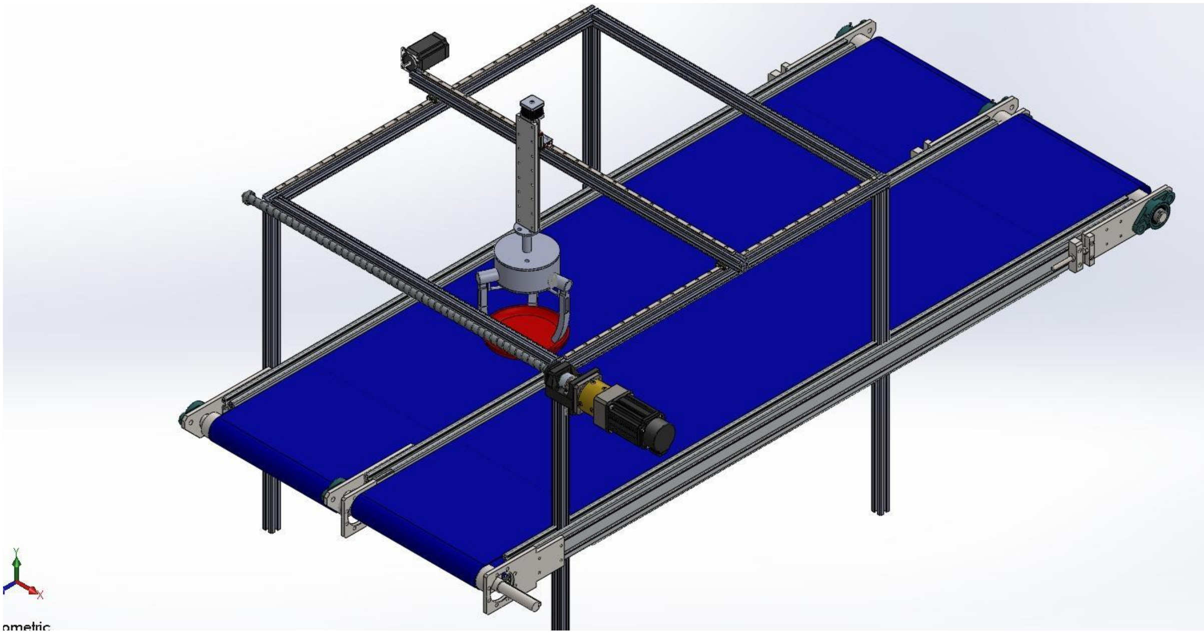

Fig 3.16 Cartesian robot with linear gripper

3.16.1 CAD model of linear gripper

The below Fig 3.16.1: Linear Gripper illustrates a 3D model of the gripper mechanism, highlighting its suitability for precise and controlled object manipulation in a Cartesian robotic system, making it ideal for automated pick-and-place operations.

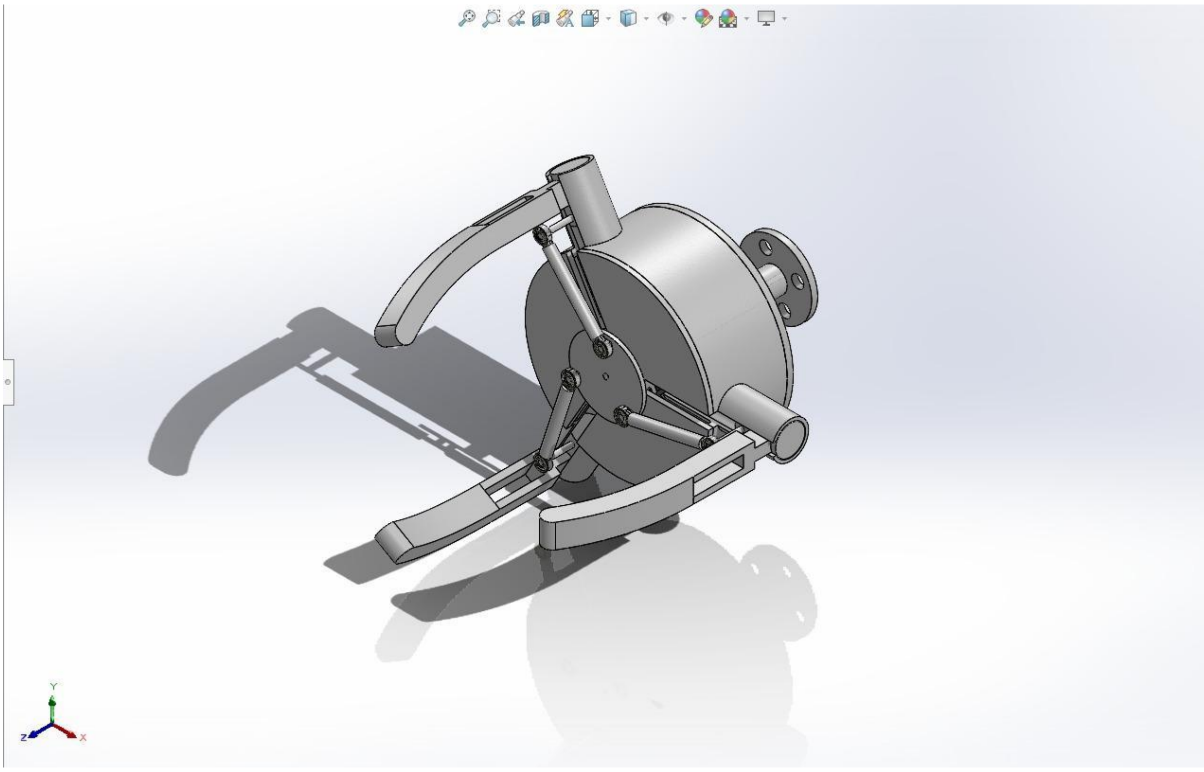

Fig 3.16.1 Linear gripper

3.16.2 Drafting of gripper parts

The below Fig 3.16.2: Linear Gripper (Top View) shows the detailed engineering drawing of the gripper, including dimensional specifications and views necessary for fabrication. This top view supports accurate assembly and integration into the Cartesian robotic system for precise pick-and-place functionality.

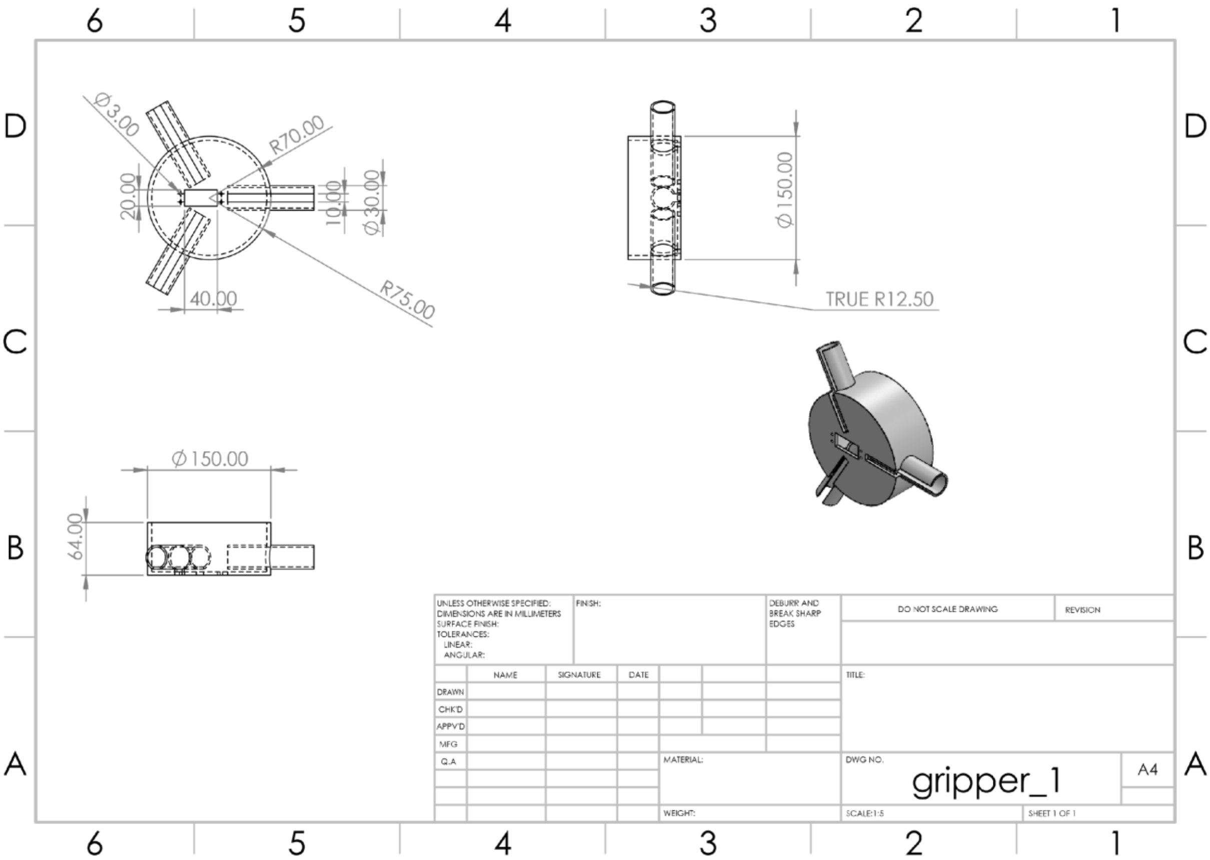

Fig 3.16.2: Drafting of linear gripper (Top View)

The below Fig 3.16.3: Linear Gripper Finger presents the dimensional drawing of an individual finger component used in the gripper assembly. This precise design ensures accurate movement and effective gripping of objects, contributing to the overall reliability and performance of the Cartesian robotic system.

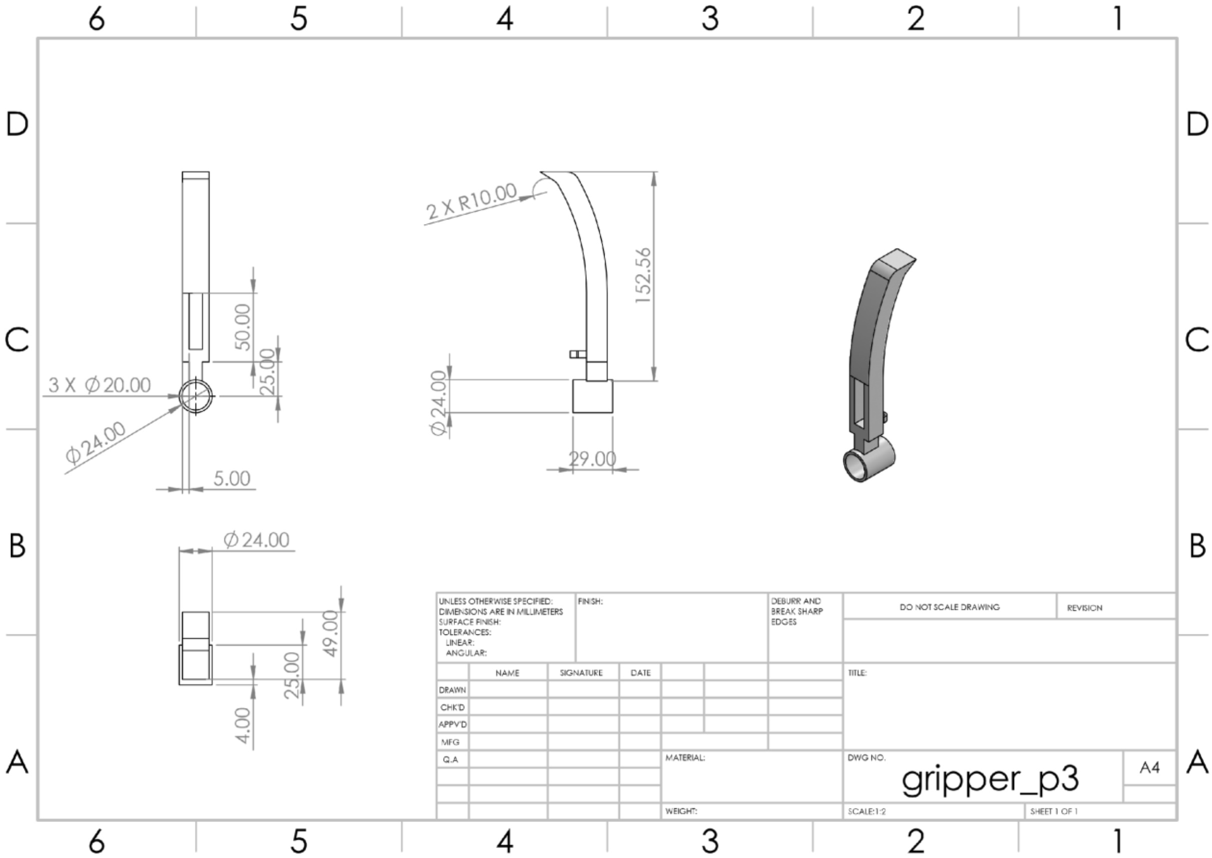

Fig 3.16.3 Drafting linear gripper finger

The below Fig 3.16.4: Linear Gripper Plate illustrates the technical drawing of the base plate used in the gripper mechanism. This component serves as the mounting platform for the gripper fingers and ensures structural support and precise alignment in the Cartesian robotic system.

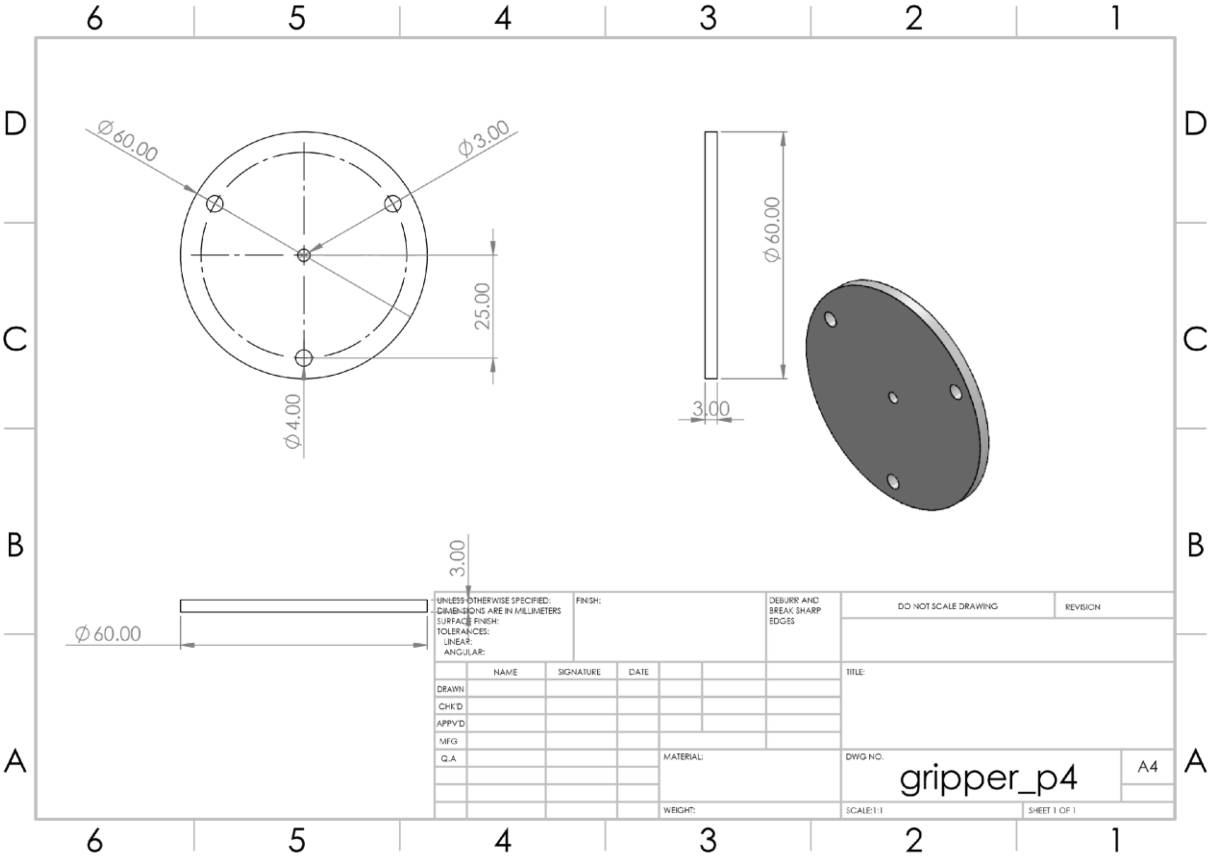

Fig 3.16.4: Drafting linear gripper Plate

The below Fig 3.16.5 Linear Gripper link illustrates the technical drawing of the link used in the gripper mechanism. This component serves as the supporting platform for the gripper fingers and ensures structural support and precise alignment in the Cartesian robotic system.

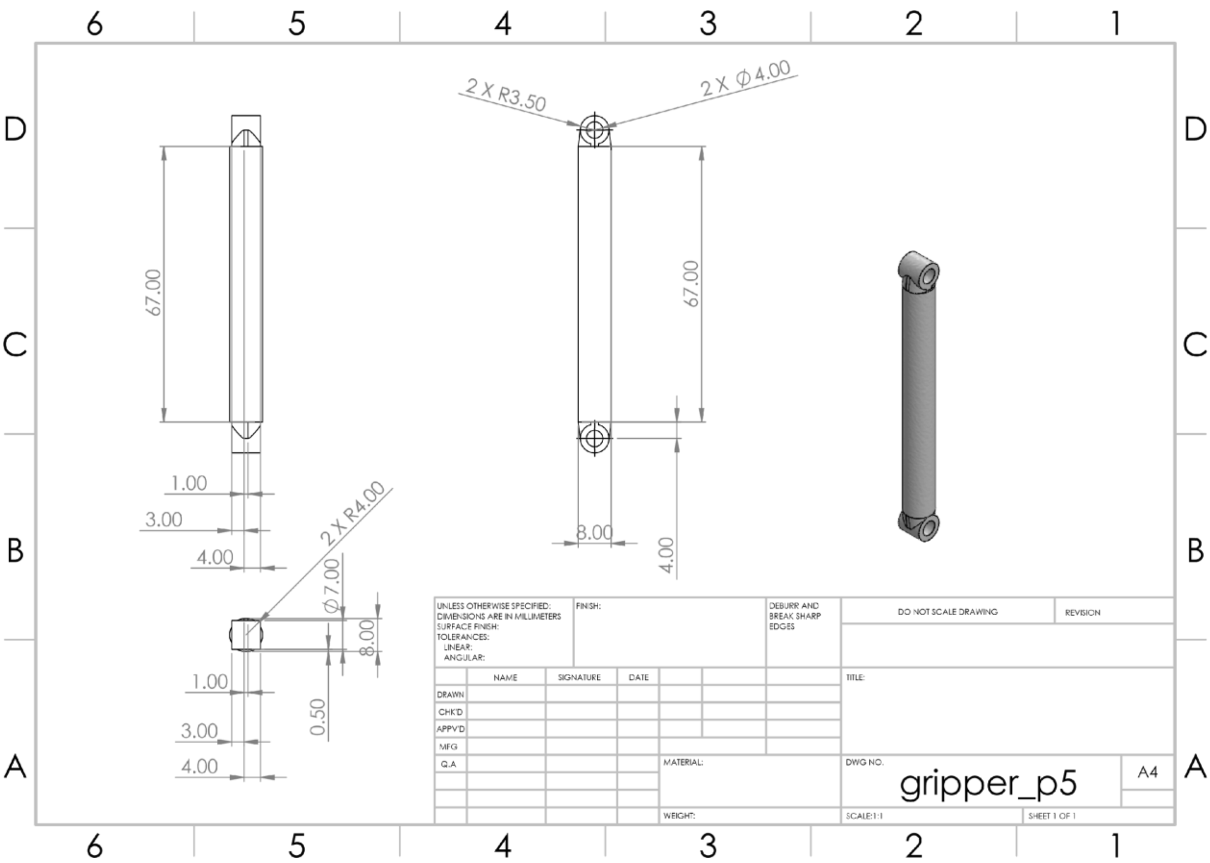

Fig 3.16.5 Drafting linear gripper Link

3.17 Drafting of Robot parts

The below fig 3.17.1 linear rail it helps to move the linear motion with the help of motor along X-axis on which Y-axis is mounted

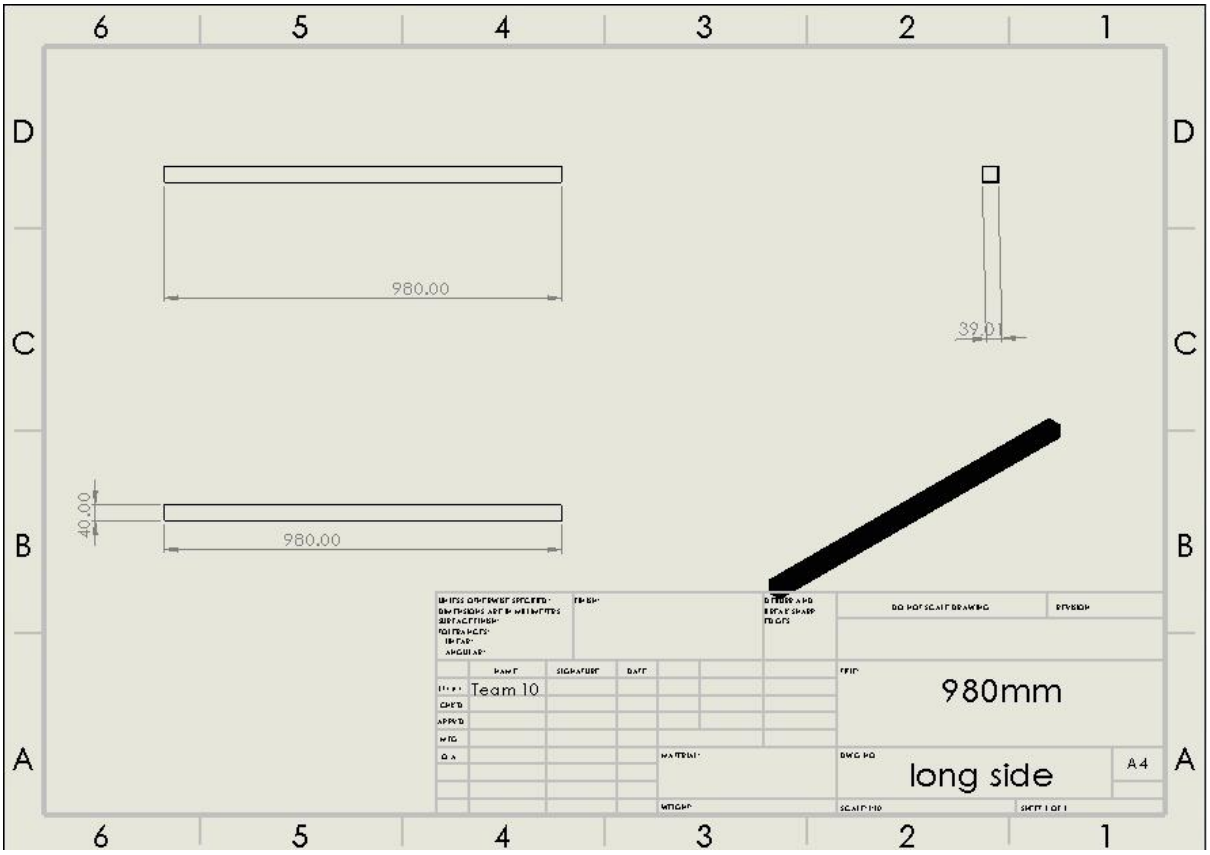

Fig 3.17.1: Drafting of Linear rail

The below fig 3.17.2: aluminium extrusion used for rigid support.

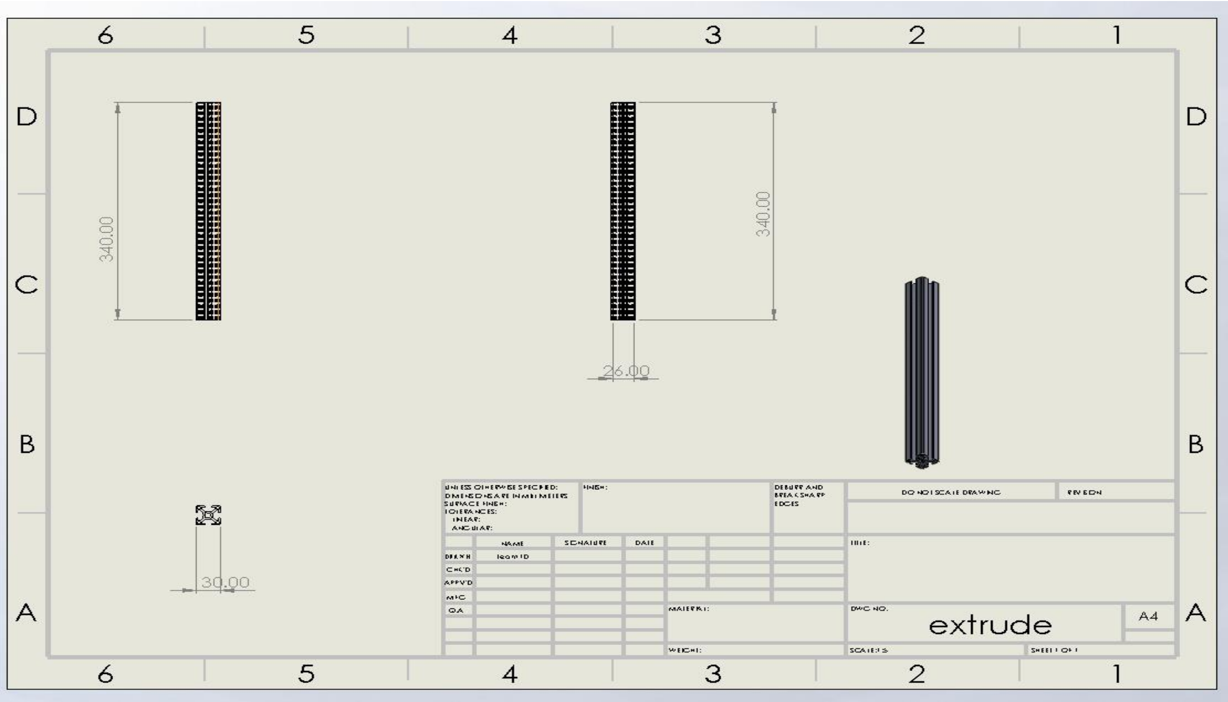

Fig 3.17.2: Drafting Aluminium Extrusion

The below fig 3.17.3 bearing mount this supports the X-axis motor rod and link parallel X-axis's.

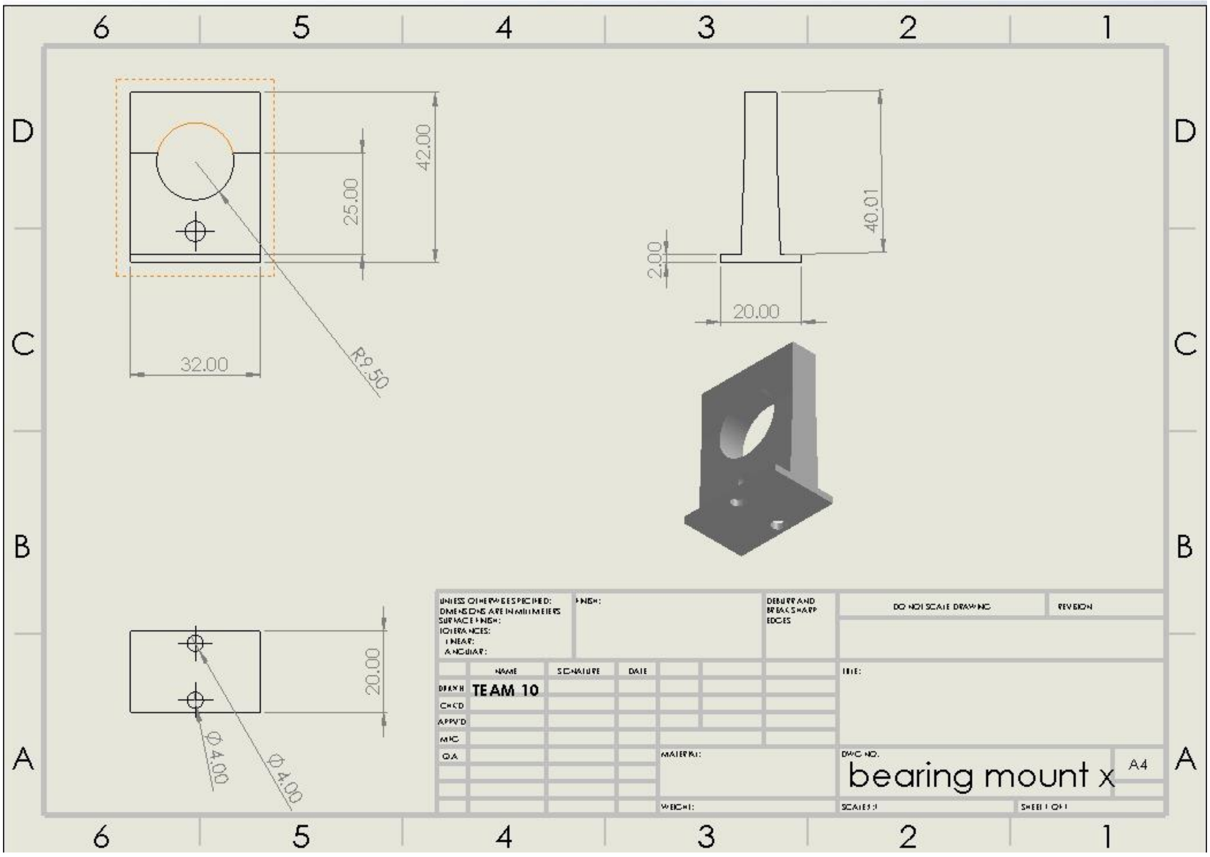

Fig 3.17.3: Drafting Bearing Mount

The below fig 3.17.4 triangle support for Z mount motor.

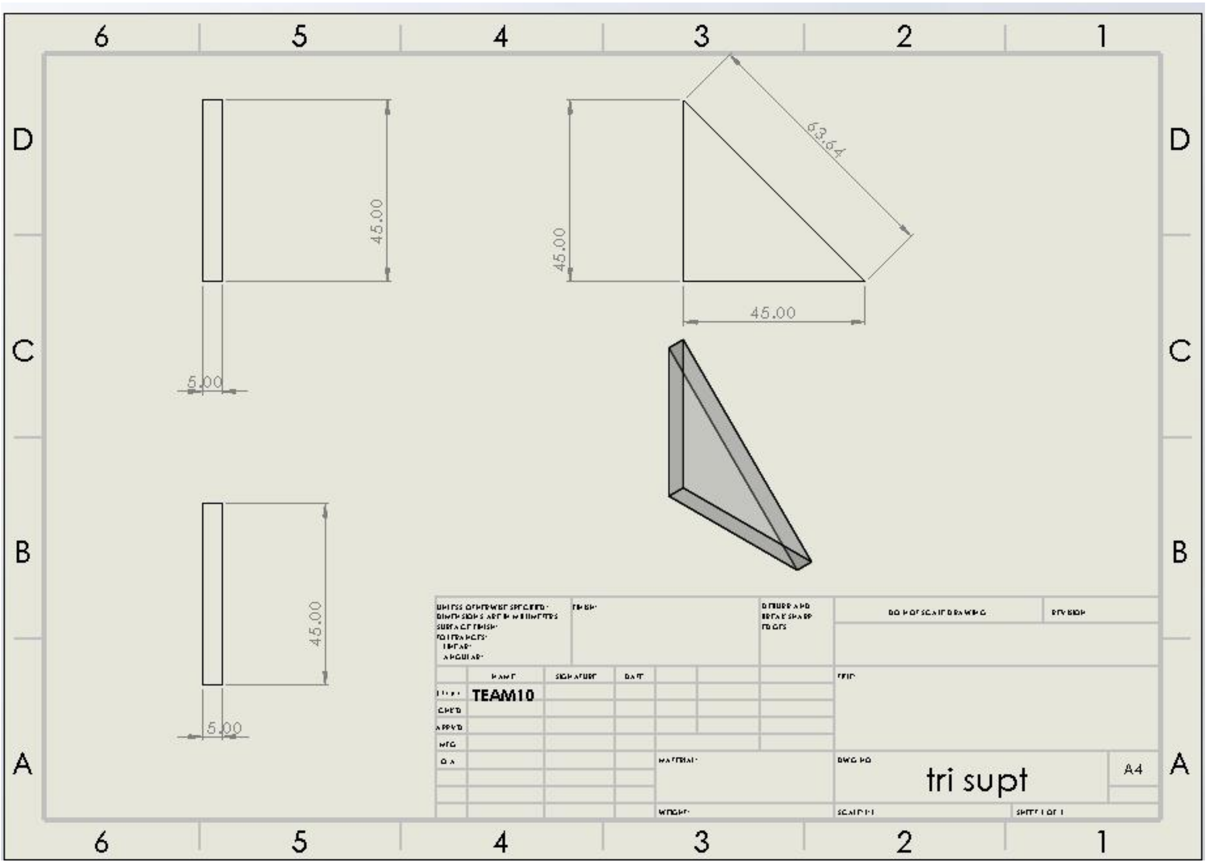

Fig 3.17.4: Drafting Triangle support.

3.18 Flow Chart

The below Fig 3.18.1 System Flow Chart illustrates the step-by-step operational sequence of the automated system, outlining the logical progression of tasks from material detection to placement.

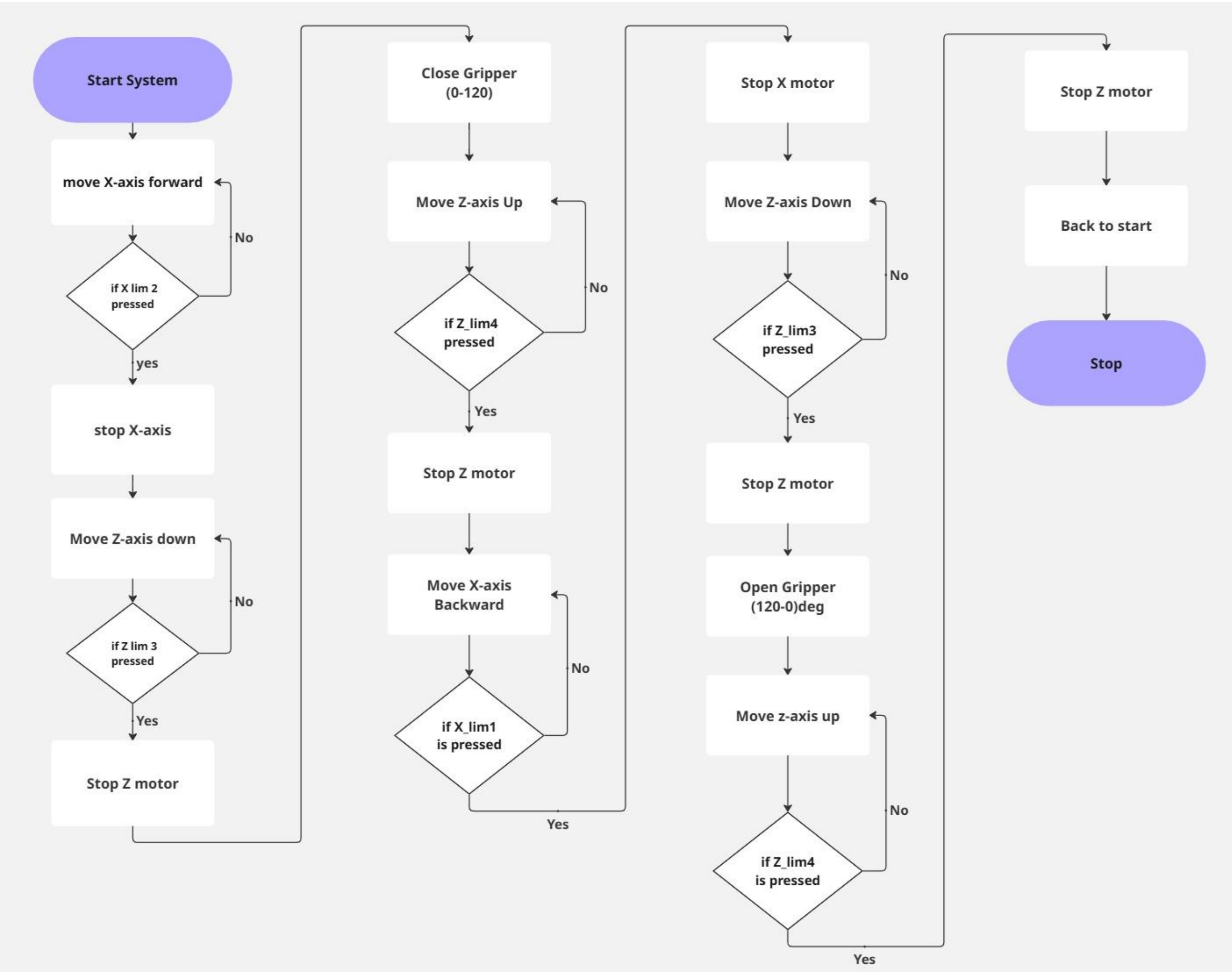

Fig 3.18.1: flow Chart

3.19 Prototype Testing

The below fig 3.19.1 represents the three-finger linear mechanical gripper capable of lifting an object weighing approximately 600 grams. It picks and places the object from one location to another within a specific time frame

Fig 3.19.1: 3-finger linear mechanical gripper

The below Figure 3.19.1 represents the assembly of a Cartesian robot integrated with a linear gripper, designed to perform precise pick-and-place operations. The system moves objects between defined locations efficiently within a specified time cycle.

Fig. 3.19.2: Assembly of a Cartesian robot with a linear gripper

4. Results

The developed Cartesian robot with a three-finger linear mechanical gripper successfully demonstrated precise and repeatable pick-and-place operations for objects weighing up to 600 grams. During extensive testing, the system consistently transferred components between predefined locations with high accuracy, minimal deviation, and excellent grip stability. The synchronized motion of the X and Z axes, combined with the firm grasping action of the gripper, ensured seamless operation throughout the task cycle. The response time, placement precision, and load handling surpassed expectations, showcasing the robustness of the mechanical design and control logic. The robot operated without slippage or misalignment, validating the reliability of the linear actuation and gripping mechanism. The use of aluminium extrusions, stepper motors, and limit switches contributed to both durability and efficiency. This result proves that the robot is not only capable of automating repetitive tasks but also scalable for real-world industrial applications requiring delicate yet firm handling.

4.1 Assembly and Integration

Mechanical components were assembled with attention to structural alignment to maintain linear accuracy. Motors, belts, rails, and the gripper were securely mounted. Electrical wiring was routed and shielded for safety and signal integrity. The control system, based on STM32 Nucleo-F401RE or Arduino, was mounted on a dedicated panel, providing reliable signal processing for motion control and real-time monitoring.

4.2 Testing and Optimization

The assembled system was tested with a simulated production setup. Payload handling of up to 600 grams was validated across multiple cycles. Gripper timing, motor speed, and sensor response were fine-tuned to optimize speed and repeatability. Adjustments were made to eliminate vibrations, ensure stable gripping, and prevent axis misalignment. The final setup demonstrated consistent and reliable operation

5.Conclusion

The Cartesian robot equipped with a three-finger linear mechanical gripper successfully fulfills its objective of precise and efficient pick-and-place operations. Capable of handling objects up to 600 grams, the system demonstrated smooth coordination between axes, stable gripping, and accurate placement. The integration of stepper motors, and aluminium frame ensured reliability, repeatability, and durability. This project highlights the potential for automation in handling lightweight components in industrial applications. With minor modifications, the system can be adapted for varied payloads or environments, making it a scalable solution for future advancements in robotic automation.

6. Future Scope

1. Integration of image processing for detecting damaged or defective objects in real-time.
2. Use of camera modules and vision algorithms to inspect shape, color, and surface defects.
3. Implementation of AI and machine learning to enable object classification and smart decision-making.
4. Enhancement of sorting capabilities based on defect severity or type.
5. Adaptation to dynamic environments using intelligent path planning and feedback.
6. Elimination of manual inspection, improving speed and accuracy.
7. Scalability for applications in manufacturing, packaging, and quality control.
8. Overall transformation into a fully autonomous, intelligent robotic system.

Team Details

SL.NO	Name	USN	Mobile Number	Personal Email ID
1	Sudev singh Hajeri	01fe22bar010	9108642343	sudevhajeri2004@gmail.com
2	Vijay Totakar	01fe22bar023	6363710519	vijaytotakar@gmail.com
3	Aditi Toravi	01fe22bar032	9113929435	adititoravi30@gmail.com
4	Paroksh Hooli	01fe22bar035	93803 22920	proxhooli@gmail.com
5	Shridevi kammar	01fe22bar038	9449972048	Shree23112003@gmail.com
6	Sohan singh Thakur	01fe22bar040	9964300264	sohansingt@gmail.com
7	Amogh Bhuti	01fe23bar416	8792596383	bhutiamogh@gmail.com

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