

DESIGN AND ANALYSIS OF MULTIPURPOSE MATERIAL HANDLING ROBOT FOR INDUSTRY PURPOSE

Pritish Chitte¹, Bhagyesh Deshmukh², Prathamesh Jadhav³ Santosh Madki⁴

¹Assistant Professor, Department of Mechanical Engineering, Walchand Institute of Technology, Solapur-413005, Maharashtra, India.

²Professor, Department of Mechanical Engineering, Walchand Institute of Technology, Solapur-413005, Maharashtra, India.

³Student, Department of Mechanical Engineering, Walchand Institute of Technology, Solapur-413005, Maharashtra, India.

⁴Assistant Professor, Shree Siddheshwar Women's College of Engineering, Solapur, 413002

Abstract

This research presents the design and analysis of a multipurpose material handling robot intended to enhance automation in manufacturing and logistics operations. The proposed robotic system integrates advanced technologies such as sensors, vision systems, and intelligent control mechanisms, enabling real-time decision-making and adaptive interaction with dynamic environments. Designed to perform functions including transferring, selecting, and relocating parts or products between workstations or machinery, the system reduces reliance on manual labour for repetitive and physically demanding tasks. This not only improves operational efficiency but also enhances workplace safety, particularly in handling heavy or hazardous materials. The study offers a comprehensive review of existing robotic material handling systems, identifying operational challenges, and proposing innovative solutions to improve system flexibility, reliability, and cost-effectiveness. By examining key factors such as automation, robotic integration, and safety strategies, the research contributes to the development of advanced, sustainable robotic solutions tailored for modern industrial requirements.

Keywords- Human safety considerations, Productivity improvement, Versatility, Intelligent control systems, Automation

INTRODUCTION

In recent years, robots have emerged as essential assets in industrial environments by automating tasks that are repetitive, labour-intensive, hazardous, or ergonomically challenging. Their integration into manufacturing, logistics, and warehousing processes significantly enhances operational efficiency, consistency, and workplace safety. The increasing demand for flexible automation has led to the development of multipurpose robotic systems capable of performing a wide range of material handling functions. This research focuses on the design and analysis of a multipurpose material handling robot tailored specifically for industrial applications. [1,2] The aim is to engineer a robust, intelligent robotic solution capable of executing diverse operations such as picking, placing, sorting, and transporting

components or products of varying shapes, sizes, and weights across dynamic workspaces. The proposed robotic system is developed with an emphasis on key design considerations such as structural rigidity, stability, load-bearing capacity, and modular adaptability. Its mechanical framework is optimized to support high-performance actuators and multi-axis joints, enabling precise and coordinated movements within complex environments. Various end-effectors, including suction-based grippers, articulated hands, and magnetic or application-specific tools, are evaluated to ensure compatibility with different types of materials and handling requirements. The integration of advanced sensing technologies—such as computer vision systems, proximity sensors, and force/torque sensors—facilitates real-time feedback, object localization, and adaptive manipulation. [3]

Additionally, intuitive human-machine interfaces and embedded safety protocols are incorporated to support seamless human-robot interaction, ensuring ease of operation and collaborative functionality. To validate the design and performance of the system, this study employs a two-phase development process involving simulation and physical prototyping. Simulation tools are used to model the robot's kinematics, workspace constraints, and interaction with the environment, allowing early identification of design flaws and optimization opportunities. Subsequently, a functional prototype is constructed and subjected to rigorous testing under controlled conditions to evaluate critical performance metrics, including cycle time, positional accuracy, repeatability, energy efficiency, and payload capacity.[4]

Beyond the design and development aspects, the paper also addresses key research gaps that hinder the widespread adoption and evolution of multipurpose material handling robots. These include the robot's ability to function reliably in unstructured or semi-structured environments, enhanced adaptive grasping of diverse and unpredictable objects, robust perception in cluttered scenes, and scalable system architectures that support task reconfiguration. Moreover, effective task planning, resource optimization, and advanced control strategies remain active areas of research with the potential to significantly boost system autonomy and intelligence. Figure 1 illustrates the various types of industrial robots commonly employed in modern industrial applications. [5] Through this comprehensive study, the research aims to contribute to the advancement of next-generation robotic solutions that are intelligent, adaptive, and applicable across a wide range of industrial scenarios, ultimately promoting sustainable automation and operational excellence. [6]

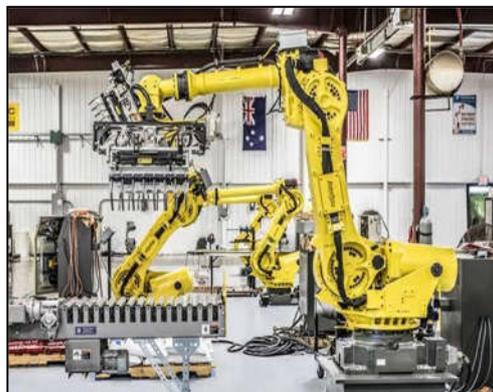


Fig 1: Industrial Robot [5]

3D CAD MODELING OF MULTIPURPOSE MATERIAL HANDLING ROBOT.



Fig 2. Multipurpose Material Handling Robot with Pneumatic gripper



Fig 3. Multipurpose Material Handling Robot with Mechanical gripper

The proposed multipurpose material handling robot is designed with a structure that mimics the human arm, incorporating three rotary joints and three wrist axes to achieve six degrees of freedom. This configuration enables precise and flexible motion, making it suitable for various industrial applications such as welding, painting, and material transfer. The 3D CAD model includes modular end-effectors—specifically pneumatic and mechanical grippers—chosen based on the material type and task requirements. Pneumatic grippers provide smooth handling of lightweight or fragile objects, while mechanical grippers offer firm control over heavier components. These configurations are shown in Figure 2 and Figure 3. The CAD model also allows for virtual simulation and motion analysis, facilitating early design validation, performance optimization, and identification of potential issues before physical prototyping. This approach ensures structural integrity, improves reliability, and supports the development of a versatile robotic system capable of adapting to a range of industrial material handling tasks.

3D CAD MODELING OF GRIPPERS OF MULTIPURPOSE MATERIAL HANDLING ROBOT.



Fig 4. Design of Pneumatic Gripper



Fig 5. Design of Mechanical gripper

The design of end-effectors plays a pivotal role in the performance of a multipurpose material handling robot. A pneumatic gripper, as illustrated in Figure 4, utilizes compressed air to actuate its jaws, allowing it to grip and release objects of varying shapes and sizes with precision. The CAD model reveals key components such as pneumatic cylinders and actuators, which are controlled using solenoid valves and pressure regulators to ensure smooth and reliable operation. In contrast, the mechanical gripper shown in Figure 5 is designed for tasks requiring high repeatability and mechanical

robustness. It consists of rigid jaws or fingers—typically arranged in parallel or custom configurations—that open and close through a geared mechanism to firmly grasp workpieces. These grippers are ideal for repetitive pick-and-place operations. The integration of such customizable gripping systems into the robotic arm enhances its versatility, allowing it to adapt effectively to diverse industrial material handling requirements.

3D CAD ASSEMBLY OF MULTIPURPOSE INDUSTRIAL ROBOT

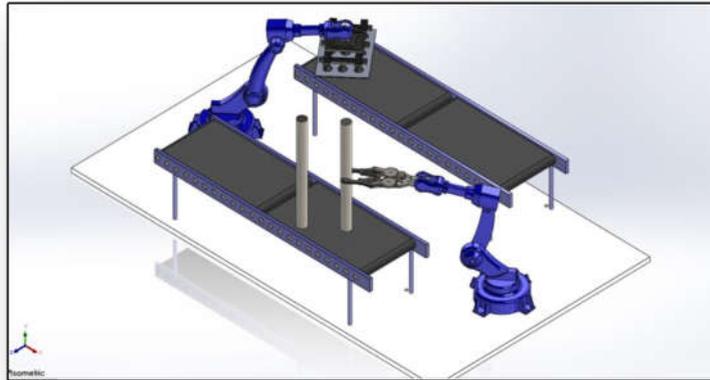


Fig 6. Design of Multipurpose Industrial Robot

The 3D CAD assembly of the multipurpose material handling robot demonstrates a fully integrated layout that simulates real-time industrial operations, including object transfer and placement on dual conveyor systems. The design incorporates two robotic arms, each equipped with different end effectors—one with a pneumatic gripper and the other with a mechanical gripper—strategically positioned to perform simultaneous pick-and-place tasks. The CAD assembly provides detailed visualization of spatial configuration, workspace overlap, and coordination between the manipulators, conveyors, and handled objects. This comprehensive digital model enables validation of motion planning, interference checks, and load distribution before physical prototyping. The modularity of the robot arms and conveyor systems enhances adaptability for diverse industrial workflows such as sorting, packaging, and assembly. Figure 6 illustrates the complete 3D CAD setup, showcasing the versatility and operational synergy between the subsystems, thereby improving productivity, reducing manual labor, and ensuring consistent precision in material handling tasks.

COMPUTER AIDED DRAFTING OF MULTIPURPOSE INDUSTRIAL ROBOT

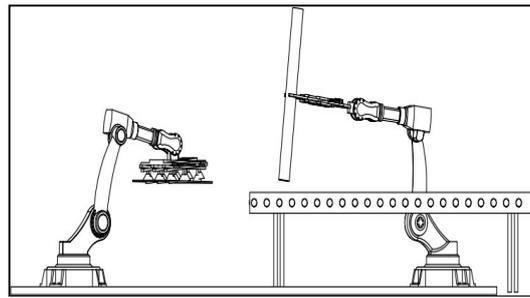


Fig 7. Computer Aided Drafting of Multipurpose Industrial Robot

The 3D CAD drafting of the multipurpose industrial robot provides an orthographic view of its spatial configuration and operational alignment with conveyor systems, aiding in precise layout planning and assembly verification. It ensures dimensional accuracy, motion range clarity, and collision-free operation, as depicted in Figure 7.

FINITE ELEMENT ANALYSIS OF MULTIPURPOSE ROBOT

Robotic Arm

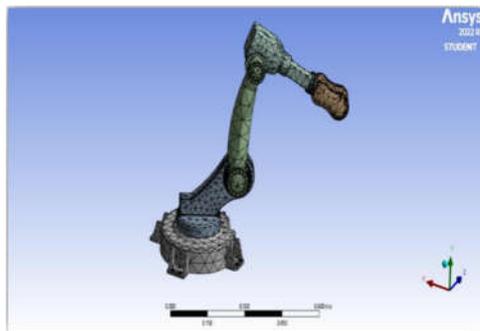


Fig 8: Meshing of Robotic Arm

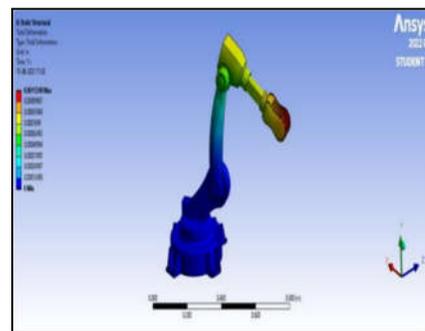


Fig 9: FEA Analysis of Meshing of robotic arm

Result – FEA Analysis of Robotic Arm

Table 1: Result - FEA Analysis of Robotic Arm

| Load in N | Deformation in mm. |
|-----------|--------------------|
| 1000 | 0.56 |
| 2000 | 1.67 |
| 3200 | Failure |

The finite element analysis (FEA) conducted on the robotic arm demonstrated that the structure can safely withstand loads up to 2000 N. At 1000 N, the arm exhibited a deformation of 0.56 mm, while at 2000 N, the deformation increased to 1.67 mm. However, when subjected to a load of 3200 N, structural failure occurred, indicating the upper limit of the arm’s load-bearing capacity. These results highlight the mechanical strength and operational safety margins of the design. The meshing and deformation distribution under different load conditions are clearly illustrated in Fig. 8 and Fig. 9, respectively.

FINITE ELEMENT ANALYSIS OF MECHANICAL AND VACUUM GRIPPER

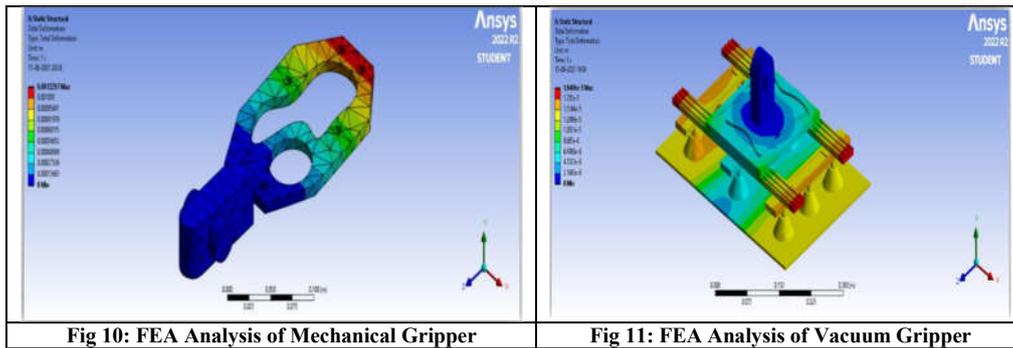


Fig 10: FEA Analysis of Mechanical Gripper

Fig 11: FEA Analysis of Vacuum Gripper

The finite element analysis of both mechanical and vacuum grippers indicates their structural viability under operational conditions. The mechanical gripper exhibits a maximum deformation of approximately 0.012259 m, concentrated at the gripping ends, which suggests flexibility in handling moderate loads (Fig. 10). In contrast, the vacuum gripper shows a minimal deformation value of 1.496e-5 m, highlighting its high stiffness and minimal structural deflection under similar loading (Fig. 11). These findings demonstrate that while the mechanical gripper is suitable for adaptable gripping tasks, the vacuum gripper offers superior precision and rigidity, making it ideal for applications requiring minimal displacement and stable positioning.

CONCLUSION

- i. The study successfully demonstrates the design and analysis of a multipurpose material handling robot optimized for industrial applications. The robot integrates advanced sensing, control, and mechanical systems to perform tasks such as picking, placing, and transporting with high efficiency and precision. CAD modeling, simulation, and FEA validated the design's structural integrity and operational performance.
- ii. Mechanical and vacuum grippers showed promising adaptability and durability under load. The results confirm the system's potential to enhance productivity, reduce human effort, and ensure safety in dynamic industrial environments, laying a foundation for scalable, intelligent automation solutions.

REFERENCES

1. Bahri, N., Reiss, J., Doherty, B., 2001. A comparison of unified vs. segregated automated material handling systems for 300 mm fabs. IEEE International Symposium on Semiconductor Manufacturing (ISSM 2001) Conference Proceedings, 19(1), 112–120.
2. Bodmer, D., Govindaraj, T., McGinnis, L., 2002. PIMSIM: Controller-based simulation and prototyping of material flow systems. International Material Handling Research Colloquium, 1–19.
3. Colvin, T., Jones, A., Hennessey, L., Mackulak, G., 1997. Fab design for 300 mm wafer handling. IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings, 25–27.

4. Bodner, D., Govindaraj, T., Karathur, K., Zerangue, N., McGinnis, L., Goetschalckx, M., Sharp, G., 2001. Expert design of industrial systems: Formalizing the design process. Proceedings of the Industrial Engineering Research Conference, 1–6.
5. <https://images.app.goo.gl/fKdMhQ7HkKw3sA7j6>
6. Gaxiola, G., Mackulak, G., 2010. Simulation analysis of a semiconductor handling and processing system: Process instability can lead to wasted modeling efforts. Proceedings of the 31st Annual Summer Computer Simulation Conference, 137–142.
7. Nazzal, D., Bodner, D., 2001. Automated material handling systems: A simulation-based design framework for automated material handling systems in 300 mm fabrication facilities. Proceedings of the 35th Winter Simulation Conference: Driving Innovation, 1351–1359.