Literature Review

1. Introduction

Industrial automation increasingly relies on robotic manipulators capable of performing repetitive material-handling tasks with high precision and reliability. Among the various applications, pick-and-place operations represent one of the most common tasks in manufacturing, packaging, and inspection systems. These tasks require robots that can accurately grasp, transport, and release objects within a defined workspace while maintaining consistent cycle times and precision.

The proposed project focuses on the design and simulation of a 4-DOF Revolute–Prismatic–Revolute–Prismatic (RPRP) robotic manipulator for such operations. This configuration combines the rotational capability of revolute joints with the linear motion of prismatic joints, enabling flexible movement in both angular and translational directions. The RPRP architecture is particularly suitable for industrial environments where components must be transferred efficiently between a conveyor belt and an assembly or inspection workstation. High positional accuracy, repeatability, and smooth motion trajectories are the core requirements of this application.

2. RPRP Manipulator Architecture and Advantages

Hybrid robotic structures, such as RPRP manipulators, bridge the gap between purely revolute and purely prismatic systems. While articulated robots provide superior dexterity, their complexity can lead to higher control requirements and limited linear reach. Conversely, Cartesian or SCARA-type robots excel in translational tasks but have constrained orientation capabilities.

The RPRP configuration offers an optimal trade-off between the two, providing:

- Rotational and linear flexibility, allowing the robot to access objects located along different planes.
- Simplified motion planning, as prismatic joints permit direct linear displacement without the need for complex rotational transformations.
- Compact workspace utilization, making the structure well-suited for confined industrial cells.
- Improved repeatability, as fewer rotational axes reduce cumulative positioning error.

These advantages make RPRP manipulators effective for tasks involving sequential pick-and-place cycles, such as sorting, assembly loading, or inspection feeding, where speed and reliability are critical.

Dynamic modeling incorporates mass, inertia, and actuator effects, forming the basis for trajectory planning, joint torque estimation, and motion smoothness. Accurate kinematic and dynamic models are essential for validating the control algorithms later tested in simulation.

4. CAD Modeling and Digital Twin Development

To translate theoretical models into a functional system, the robot's physical structure will be modeled in SolidWorks or Fusion 360. The CAD phase defines link dimensions, joint constraints, and the end-effector interface suitable for a lightweight gripper. The model is then exported into a format compatible with simulation environments, serving as the foundation for a digital twin—a virtual representation of the physical manipulator. This digital twin allows iterative testing of design parameters such as link lengths, workspace coverage, and payload handling capacity before hardware implementation, thus reducing prototyping costs and time.

5. ROS 2 and MuJoCo Integration

ROS 2 (Robot Operating System 2) provides the communication and control infrastructure for robotic applications. It enables modular development through nodes, topics, and services, and includes packages such as ros2_control and MoveIt 2 for motion control and trajectory planning. Within this framework, the RPRP manipulator will be integrated as a complete robot description, incorporating URDF/Xacro files, joint controllers, and motion planning configurations. MuJoCo (Multi-Joint dynamics with Contact) complements ROS 2 by offering a high-fidelity physics simulation environment capable of modeling joint dynamics, contact forces, and actuator responses in real time. Through MuJoCo, the manipulator's behavior under different control strategies can be accurately visualized and analyzed. The simulation setup involves configuring joint controllers, defining material properties, and tuning physics parameters to ensure realistic motion. Subsequently, ROS 2 control nodes, implemented in Python or C++, will be used to command pick-and-place trajectories. These experiments will evaluate path smoothness, precision, and collision-free motion, reflecting the manipulator's real-world performance potential.

6. Conclusion

In summary, the proposed project integrates mechanical design, analytical modeling, and advanced simulation tools to develop a comprehensive framework for an industrial pick-and-place RPRP manipulator. The hybrid joint configurationd MuJoCo enable an efficient simulation and control pipeline. This literature review establishes the theoretical and technological context for the project. Future milestones will focus on the derivation and validation of forward and inverse kinematics, CAD refinement, ROS 2 package creation, and dynamic testing in MuJoCo to achieve accurate and repeatable pick-and-place performance.

References

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