DragonPassEngineer: Self-Designed Robot for Material Pickup and Delivery

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Abstract

With the advancement of the Fourth Industrial Revolution, robotics technology has been continuously evolving towards greater intelligence and precision, becoming a vital support force in industrial and service sectors. Aiming to address the current limitations of household service robots, which often perform only single and simple tasks, this study focuses on developing a multifunctional six-degree-of-freedom serial collaborative robotic arm service platform. The platform is designed to enable simultaneous execution of multiple household service tasks and can be expanded with functional modules based on practical needs. This research first reviews the current status and trends of robotic structural development both domestically and internationally, and clarifies the research content and chapter arrangement of this project. Subsequently, based on system design requirements, the study provides a detailed analysis of system logic demands, fundamental parameters, and hardware configuration, and completes the mechanical design calculations for linkages, drives, and pneumatic circuits. Through simulation and real-world prototype testing, the performance and feasibility of the designed system are verified. Ultimately, the proposed robotic arm system demonstrates strong modular expandability and offers valuable references for multi-task collaborative applications in both household and industrial fields. The related code and materials can be found in our repository

1 Introduction

Robots have begun to enter our daily lives as household appliances, but predominantly in the form of single-purpose devices. Common examples include robotic vacuum cleaners and lawnmowers, which are typically confined to one repetitive task [Shiokawa et al., 2025]. These domestic robots often remain idle for long periods outside of their primary function [Shiokawa et al., 2025], indicating untapped potential for additional utility. Indeed, floor-cleaning robots (vacuuming and mopping units) alone account for roughly 81% of the household robot market [Mordor Intelligence, 2024], underscoring how current home robotics are heavily specialized and lack generalization beyond narrow chores.

There is a growing need for general-purpose household robots that can perform a variety of tasks by combining mobility and manipulation capabilities. Developing the next generation of home assistants requires integrating locomotion with interactive skills—an approach known as mobile manipulation

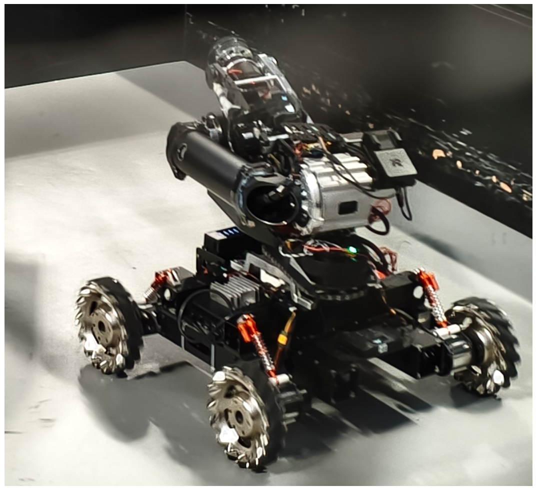

Figure 1: Prototype of DragonPassEngineer

[Hu et al., 2023]. This enables a robot not only to navigate the home but also to physically interact with objects and appliances, tackling complex chores that single-function robots cannot handle. Recognizing this need, industry leaders and researchers are shifting focus toward more versatile home robots. For example, Dyson has signaled a "big bet" on robots capable of performing household chores by 2030, moving beyond dedicated vacuum cleaners to robotic arms that can wash dishes or tidy up [Jolly, 2022]. On the research side, platforms like Willow Garage's PR2 demonstrated the value of mobile manipulators for household tasks, but its high cost (around $400k) meant such general-purpose robots remained confined to laboratories [Ackerman and Guizzo, 2020]. Recently, newer systems have emerged that aim to be compact and affordable without sacrificing capability. Notably, Hello Robot's Stretch is a lightweight mobile manipulator designed to operate in home environments; while initially a research platform, its creators hope to deploy it in real homes to assist people in everyday tasks [Ackerman and Guizzo, 2020]. These trends highlight the significance of developing a general-purpose home robot that combines mobility and manipulation to broaden the scope of domestic automation.

In this work, we design, develop, and deploy a household robot named DragonPassEngineer, whose prototype is shown in Figure 1, with generalizable task capabilities, uniquely integrating an omnidirectional mobile chassis and a robotic arm with a suction-based gripper. The robot's base uses a holonomic drive (motorized omnidirectional casters), allowing it to move freely in any direction without the kinematic constraints of a typical differential-drive base [Wu et al., 2024]. This enhanced maneuverability makes it easier to reposition in tight or cluttered spaces, improving efficiency when performing chores in a domestic environment [Wu et al., 2024]. Mounted on this agile base is a 6-degree-of-freedom manipulator arm actuated by high-torque servo motors. We leverage the ROS MoveIt SDK for motion planning and control of the arm, enabling flexible planning of both base and arm movements in tandem. For the end-effector, we opted for a vacuum suction cup gripper due to its robustness and accessibility. Vacuum-based end effectors are widely used in industry and often preferred over two-finger grippers because they can securely lift objects with a single point of contact [Mahler et al., 2018]. This design offers a reliable grip on a variety of everyday items and can even reach into narrow or irregular spaces that might thwart parallel-jaw grippers [Mahler et al., 2018]. Together, these design elements—holonomic mobility, a servo-driven arm with advanced motion planning, and a suction cup gripper—equip our robot with the generality and reliability needed to handle diverse household tasks.

We validate our robot through real-world conceptual testing on representative household tasks. In preliminary trials, the platform was able to navigate a home-like environment and perform basic manipulation duties such as picking up objects from the floor, placing items on a shelf, and opening cabinet doors. This proof-of-concept demonstration illustrates the feasibility of a single robotic system addressing multiple common chores. Notably, contemporary research has reported success with similar mobile manipulators executing household tasks: for instance, a holonomic mobile manipulator was shown to open a fridge, wipe a countertop, and load a dishwasher after minimal training demonstrations [Wu et al., 2024]. Such results underscore the potential of a general-purpose household robot that can adapt to various tasks. By combining mobility and manipulation in an integrated platform, our work aims to push beyond the limitations of today's single-purpose robots and toward versatile assistants capable of robustly handling the wide range of duties found in everyday home life.

2 Mechanism Design

2.1 Mechanism Overview

Table 1 lists out the functional parameters of our mechanism design in details. The robotic system integrates a structured division of control, power, and mechanical design to ensure stable operation and precise motion execution.

Name	**Functional Parameters**
Total Weight (kg)	22.5
Arm Weight (kg)	10.74
Dimensions (mm, L-W-H)	Folded: 555-520-440 Extended: 1100-1100-1080
Arm Structure Type	Articulated Manipulator + Wrist
Degrees of Freedom	6 DOF
End-Effector Payload	1.5 – 2 kg
Arm Actuators and Travel Range	**(Actuator – Drive Type – Range)**
J0	MG8016E (Internal 6:1 planetary gear) – Chain drive – 1:1 (0° – 360°)
J1	MG8016E (Internal 6:1 planetary gear) – Chain drive – 1:1 (–102.5° – 77.5°)
J2	MF7025V2 (28T) – Cable-driven – Reduction 41:1 (–25° – 155°)
J3	MF7025V2 (10T) – Cable-driven – Reduction 31:1 (–5° – 229°)
J4	DM4340 (Internal 40:1 planetary gear) – Direct drive – (0° – 360°)
J5	DM4310 (Internal 10:1 planetary gear) – Direct drive – (30° – 330°)
J6	DM4310 (Internal 10:1 planetary gear) – Direct drive – (0° – 360°)
Chassis Type	**Mecanum Wheel Chassis + Independent Suspension**
Chassis Passability	Approach Angle: 40° Breakover Angle: 40.2° Departure Angle: 39.2°
Chassis Mobility	Travel Speed: Linear 2.5 m/s; Angular 20 rad/s Acceleration: Linear 5 m/s^2; Angular 20 rad/s^2
Suction Response Time	0.5 s
Pneumatic Parameters	Air Pumps: 2 × maxon-D2248LPR11.0 dual-head brushless diaphragm pumps Working Vacuum: –50 kPa Flow Rate: 30 L/min Number of Suction Cups: 3
Electrical Parameters	Power Supply: 1 × 24V 4500 mAh Smart Battery

Table 1: Functional Parameters of DragonPassEngineer

System Control The robotic platform employs a dual-microcontroller architecture using two `STM32` units to manage base-level motion control and peripheral coordination. High-level processing tasks, including robotic arm pose estimation and real-time correction through visual feedback, are offloaded to an onboard `Intel NUC`. This distributed computing framework enables modular control and responsive motion adaptation.

Power Distribution A centralized 24 V high-current power supply supports both the chassis and the robotic arm. To maintain electrical safety and prevent voltage backflow under dynamic loading, the main supply circuit is equipped with a relay switch and diode protection module. The NUC receives stable operating voltage through a dedicated DC-DC step-down converter.

Electrical Isolation and Wiring Management To achieve electrical isolation and reduce communication interference between the chassis and the arm, the system utilizes a dual-layer slip ring design. One slip ring is responsible for power transmission to the robotic arm, while the other facilitates upper-layer data communication, effectively minimizing electromagnetic interference. An onboard distribution board equipped with aviation-grade connectors provides modular wiring separation, mechanical decoupling, and improved reliability.

Chassis Drive System The mobile base adopts a four-wheel omnidirectional drive using mecanum wheels, offering high maneuverability. Each wheel is independently controlled by a dedicated motor driver, enabling precise translation and rotation in complex environments. The base achieves a linear speed of up to 2.5 m/s and angular velocity of 20 rad/s, with corresponding accelerations reaching 5 m/s^2 and 20 rad/s^2, respectively.

Robotic Arm Actuation The 6-DOF articulated robotic arm, integrated with a wrist joint, is actuated through a combination of chain drives and cable-driven reducers, as outlined in the system specifications. The actuators include a series of `MG8016E`, `MF7025V2`, and `DM4310/4340` motors configured with planetary gearboxes and direct or cable drive modes depending on joint placement. The arm supports an end-effector payload of $1.5-2$ kg. Parallel actuation includes dual `maxon-D2248LPR11.0` diaphragm vacuum pumps used for object suction, which are controlled via relays to allow coordinated gripping during manipulation tasks.

2.2 System Topology and Integration

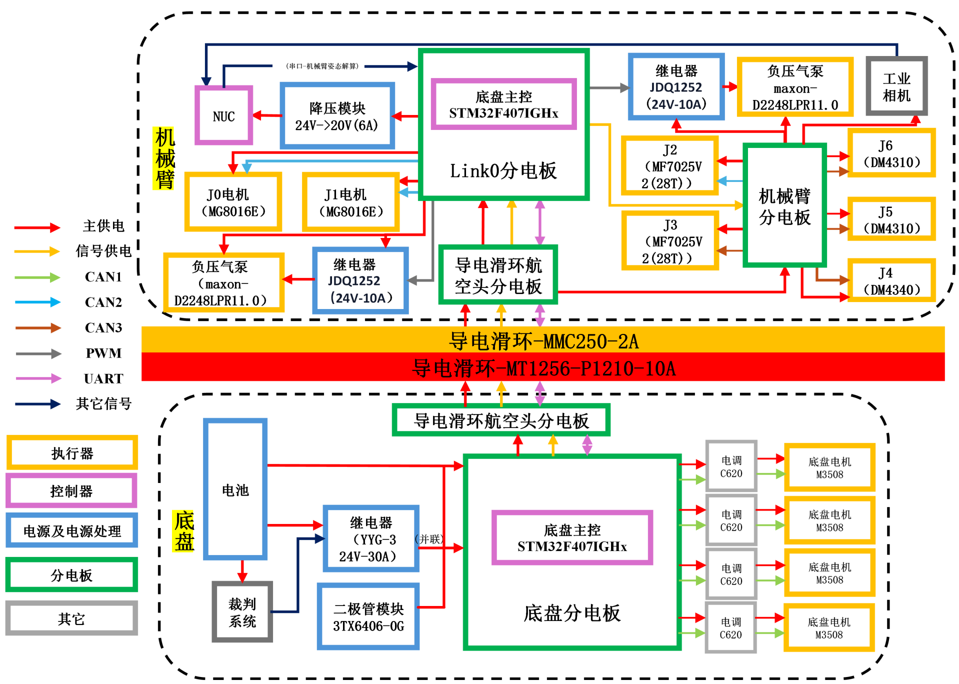

Figure 2: Mechanism Topology of DragonPassEngineer

The overall hardware system architecture is illustrated in Figure 2. The design features a clear modular separation between the chassis and the robotic arm subsystems, interconnected via a dual-channel slip ring (MMC250-2A for power, MT1256-P1210-10A for communication). Each subsystem contains independent power management, signal routing, and execution units.

The chassis is powered by a high-current battery system with a main relay and diode protection module, distributing 24 V power to the base motor drivers (C620) that control four M3508 wheel motors. The STM32F407IGHx controller handles chassis motion via a dedicated base-level distribution board.

The robotic arm subsystem is powered and controlled through a parallel branch, where its own STM32 unit interfaces with multiple actuators (MG8016E, MF7025V2, DM4310/4340) via relays and performs real-time task execution under coordination from the onboard NUC. Visual feedback and vacuum pump control are also tightly integrated into this topology. Aviation-grade distribution boards facilitate structured wiring and logical decoupling of components.

3 Control System Design

Robotic arms are pivotal in applications ranging from industrial automation to medical surgery, necessitating precise control to execute complex tasks. The design of control systems for such arms involves challenges in modeling dynamics, planning motions, and ensuring real-time responsiveness. Traditional methods often treat simulation, planning, and control as separate entities, leading to inefficiencies and integration difficulties.

This section proposes a unified control system design that integrates high-fidelity physics simulation, real-time communication middleware, advanced motion planning, and realistic object interaction simulation. The design leverages MuJoCo for dynamics simulation, ROS2 for communication, MoveIt2 for motion planning, and Unity for interaction simulation. A Proportional-Derivative (PD) control law operating at 1000 Hz provides the necessary feedback for precise control. The objectives of this design are to achieve:

- Accurate simulation of robotic arm dynamics.
- Efficient communication between system components.
- Optimal motion planning for complex tasks.
- Realistic simulation of object interactions.
- Real-time control with high-frequency feedback.

This integrated approach offers a robust framework for controlling robotic arms in dynamic environments.

3.1 Platform Components

The control system comprises four primary components referred in Fig. 3, each serving a distinct function:

- **MuJoCo: High-Fidelity Physics Engine**
  MuJoCo simulates the robotic arm's dynamics with high accuracy. It models physical interactions, including joint movements, forces, and constraints, providing a realistic environment for testing control algorithms. The simulation environment features a grid-based workspace with a multi-jointed robotic arm, rendered with articulated segments.
- **ROS2: Communication Middleware**
  ROS2 serves as the communication backbone, utilizing the DDS protocol for real-time data exchange. It connects the simulation, planning, and interaction modules, handling data such as joint states, commands, and sensor readings.
- **MoveIt2: Motion Planning Core**
  MoveIt2, integrated with OMPL, is the motion planning module. It generates collision-free paths and optimizes trajectories based on input from ROS2, ensuring precise control of the arm's end-effector. It processes user commands to compute target joint positions.
- **Unity: Object Interaction Simulation**
  Unity simulates interactions between the robotic arm and objects in a virtual environment.

It includes scenarios such as manipulating a pump, allowing for validation of the arm's manipulation capabilities in a controlled 3D space.

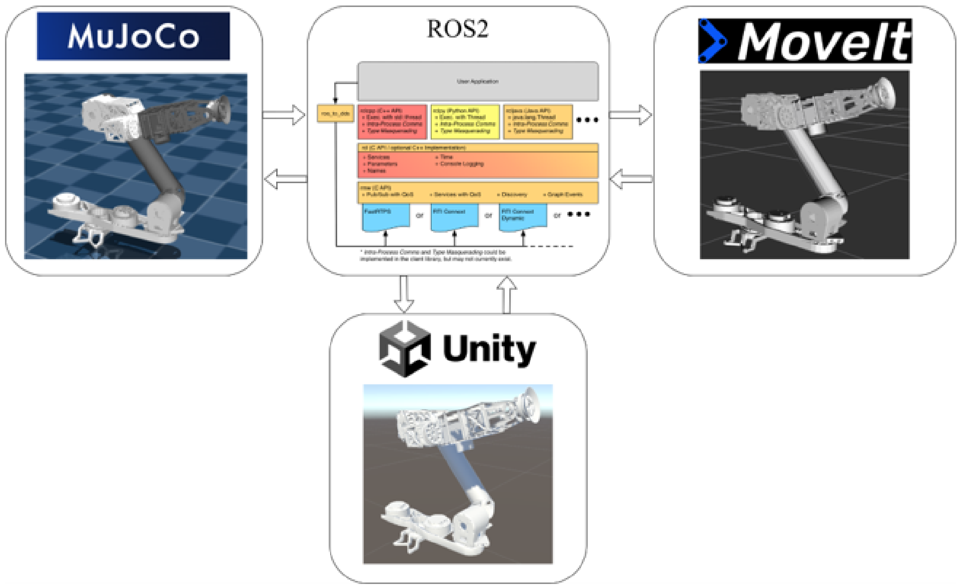

Figure 3: Overview of Sim-to-Real Verification Platform

3.2 System Architecture

The system architecture forms a closed-loop framework, which shown in Fig. 4:

- MuJoCo simulates the arm's dynamics and sends state data to ROS2.
- ROS2 distributes this data to MoveIt2 for motion planning and Unity for interaction simulation.
- MoveIt2 computes optimal trajectories based on user commands and current states, sending planned motions back to ROS2.
- ROS2 updates MuJoCo with control inputs, adjusting the simulation in real-time.
- Unity provides feedback on object interactions, incorporated via ROS2.

This interconnected design ensures adaptability and precise control.

3.3 Control Algorithm

A PD control strategy regulates the robotic joints. The control input is calculated as:

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt}, \tag{1}$$

where $e(t)$ is the error between target and actual joint positions, K_p is the proportional gain, and K_d is the derivative gain, ensuring stability and responsiveness.

The control loop operates at 1000 Hz, aligning with real-world controller requirements. This high frequency enables rapid adjustments, critical for dynamic tasks.

3.4 Feedback Mechanism

Feedback occurs via:

- **Simulation Feedback**: The MuJoCo PD controller adjusts inputs based on simulated joint positions.

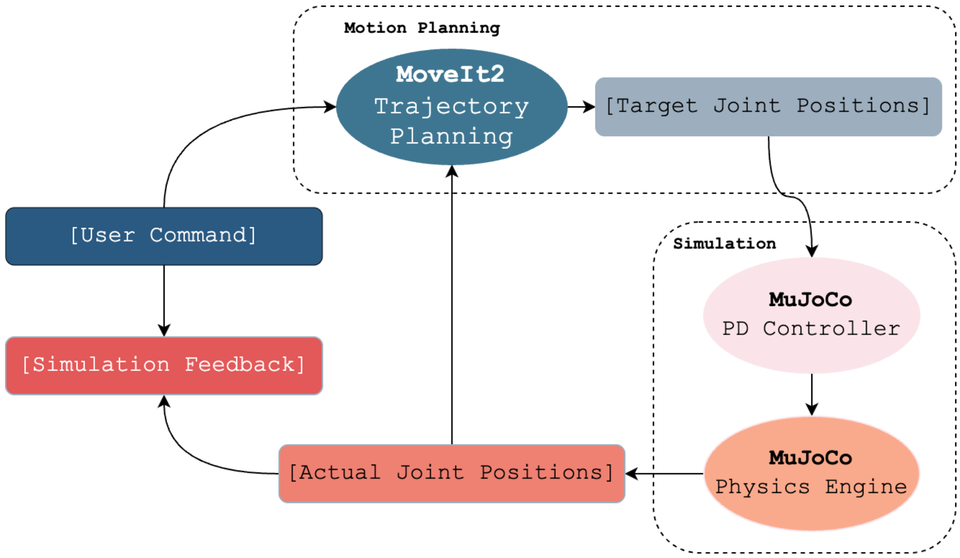

Figure 4: Overview of Control System Components

- **Actual Joint Positions**: The MuJoCo physics engine provides actual joint position data, fed back for continuous correction.

This dual feedback ensures accurate tracking of target positions.

The proposed control system integrates MuJoCo, ROS2, MoveIt2, and Unity with a high-frequency PD control law to achieve precise robotic arm control. This framework supports both research and industrial applications, with future work focusing on optimizing control parameters and expanding capabilities.

4 Simulation

4.1 Simulation Environment

To investigate the grasping performance of the proposed robotic system without the cost and safety constraints of physical trials, we developed a high-fidelity, closed-loop simulation platform that combines the strengths of four mature open-source frameworks: MuJoCo, Unity 3D, MoveIt 2, and ROS 2. Each component fulfils a distinct role in the pipeline; together they deliver real-time, physics-plausible interaction for both the robot and its environment.

MuJoCo 2.3.7 – Multibody Dynamics Core MuJoCo serves as the authoritative rigid-body physics engine. All links of the 6-DoF manipulator, the wrist-mounted vacuum gripper, and the target objects are modelled in a single `.mjcf` file. The simulator is advanced at $1\,\mathrm{kHz}$ with a $0.5\,\mathrm{ms}$ timestep, ensuring stable contact dynamics even under the high stiffness values required for accurate force–torque estimation. Custom MuJoCo callbacks inject joint torques computed by MoveIt 2 (described below), and read back proprioceptive states that are published to ROS 2 at $250\,\mathrm{Hz}$.

Unity 2022.3 – Photorealistic Front-End and Aerodynamic Proxy Although MuJoCo provides accurate contact dynamics, it lacks facilities for aerodynamic or suction phenomena. Unity therefore acts as a visual front-end and as a proxy for the vacuum pump. The robot's and objects' meshes are imported via the ROS–Unity URDF importer; their poses are updated synchronously from MuJoCo through a lightweight TCP bridge. When the gripper's vacuum is activated in Unity, a collision-based trigger links the object to the tool flange by creating a temporary fixed joint in the Unity scene. This event is simultaneously broadcast to ROS 2 and forwarded to MuJoCo, where an equivalent weld constraint and an upward suction force (estimated from the pump's datasheet curve) are applied. Using Unity in this manner preserves the visual realism of floating-point shaders and particle-based suction effects while allowing MuJoCo to remain the single source of truth for physical consistency.

MoveIt 2 – Motion Planning and Kinematics MoveIt 2 provides high-level manipulation capabilities, including self-collision checking, inverse kinematics, and trajectory optimisation. The URDF/XACRO model used by MoveIt 2 is auto-generated from the same source files as the MuJoCo model to guarantee geometric consistency. For each pick-and-place cycle, MoveIt 2 samples a set of grasp poses around the object, ranks them via the *minimum-jerk* cost functional, and solves time-optimal trajectories using the Time-Optimal Trajectory Generation (TOTG) plugin. The resulting joint position, velocity, and torque profiles are streamed to MuJoCo as feed-forward commands at $250\,\mathrm{Hz}$.

ROS 2 Humble – Middleware and Synchronisation Layer All inter-process communication is orchestrated by ROS 2 Humble, chosen for its deterministic DDS transport and native support in both MoveIt 2 and Unity's ROS–TCP package. The simulation loop comprises three key nodes:

1. `mujoco_driver`: publishes joint states, subscribes to commanded torques, and relays suction-force events.
2. `unity_bridge`: converts ROS messages to Unity's coordinate system and vice-versa.
3. `control_manager`: spawns MoveIt 2 planning instances, supervises vacuum activation, and logs metrics.

Clock synchronisation is achieved by designating MuJoCo as the time master; its simulation step emits a latch / release signal that throttles all downstream ROS 2 publishers, thereby eliminating race conditions between physics updates and Unity rendering.

Vacuum Pump Modelling The desktop-scale vacuum pump (max. $-85\,\mathrm{kPa}$, nominal flow $12\,\mathrm{L\,min^{-1}}$) is approximated as a quasi-static pressure differential that generates a net suction force

$$F_{\text{vac}} = A_{\text{seal}}\,\Delta P,$$

where A_{seal} is the effective sealing area derived from the CAD geometry and ΔP is the pump's instantaneous pressure. A lookup table extracted from the manufacturer's characteristic curve maps pump duty cycle to ΔP. The force is applied along the local z-axis of the gripper flange in MuJoCo; Unity mirrors the effect visually by driving a particle-based airflow shader. This hybrid representation captures both the mechanical load on the manipulator and the visual feedback useful for operator training.

Real-Time Performance On a workstation equipped with an AMD Ryzen 7 7800X3D CPU and an NVIDIA RTX 3080 GPU, the combined system runs faster than real time by a factor of $1.8\times$ (MuJoCo $\approx$ 0.45 ms/step, Unity render $\approx$ 3.5 ms/frame at $120\,\mathrm{Hz}$). The end-to-end latency between a planned trajectory in MoveIt 2 and its manifestation in Unity is below $10\,\mathrm{ms}$, well within the limits required for closed-loop visual servoing in future work.

4.2 Simulation Results

The result can be viewed as Fig. 5, Fig. 6, Fig. 7 .

5 Experiments

5.1 Experiment Settings

To evaluate the robot's manipulation and mobility capabilities in a realistic domestic context, we conducted a pickup-and-delivery task within a $5\,\mathrm{m} \times 5\,\mathrm{m}$ bounded workspace. The robot was instructed to autonomously navigate to predefined object locations, pick up cubic props with approximate dimensions of $200\,\mathrm{mm} \times 200\,\mathrm{mm} \times 200\,\mathrm{mm}$ using the suction-based end-effector, and transport them to designated drop-off zones. Each drop-off zone contained cartons of corresponding sizes to simulate household sorting or organization tasks. The robot was controlled via a servo-based gamepad interface, allowing us to validate system responsiveness, object-handling reliability, and maneuverability in a constrained environment.

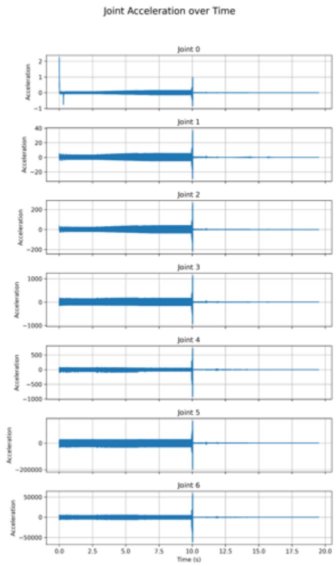

Figure 5: Joint Acceleration

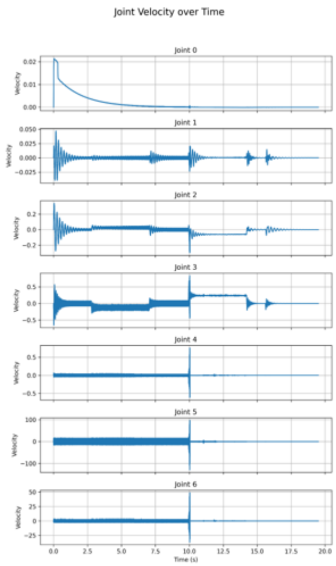

Figure 6: Joint Velocity

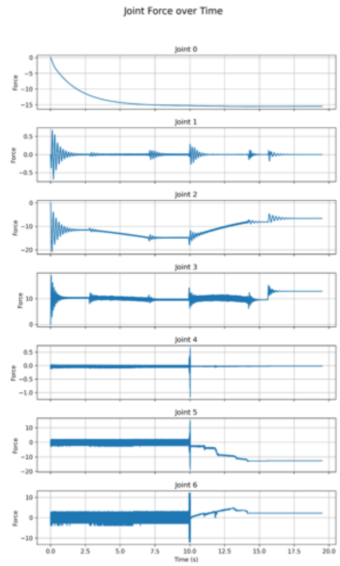

Figure 7: Joint Force

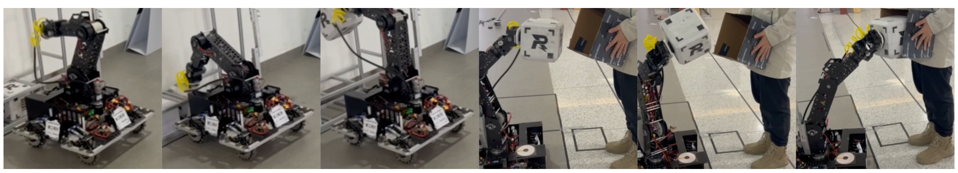

Figure 8: Experiment Snapshot of Validation Task

5.2 Function Validation

As shown in Figure 8, the robot successfully completed the object pickup and delivery task under real-world conditions. Operating within a 5 m × 5 m workspace, it retrieved cubic props (200 mm per side) and placed them accurately into designated cartons using its suction-based end-effector. The task was performed under servo-based gamepad control, validating both the system's mechanical reliability and the responsiveness of the integrated control architecture. The entire task sequence—from initial pickup to final placement—was completed in 1 minute and 42 seconds. This result demonstrates the effectiveness of our hardware-software integration in achieving reliable mobile manipulation in a constrained environment.

6 Conclusion

This project presents the design, development, and deployment of a task-generalized household robot that integrates a holonomic mobile chassis, a robotic arm, and a suction-based end-effector. Through a series of tightly coupled subsystems, we successfully built a mechanism-level hardware architecture and developed a complete control stack based on `ROS2`, `MoveIt`, and `MuJoCo`. Simulation and visualization were carried out using Unity, enabling efficient debugging and system tuning. For real-world validation, the robot was actuated via servo-based gamepad control and demonstrated the ability to perform representative household tasks, such as object pickup and delivery.

Despite these achievements, we also admit that the current system has certain limitations. First, the pneumatic suction cup exhibits limited payload capacity, constraining the diversity of objects the robot can handle. Second, the robotic arm currently supports only speed and position control modes. Introducing force control in future iterations could enhance interaction safety and broaden the system's manipulation capabilities, especially in tasks involving delicate or compliant objects.

Moving forward, our goal is to continue improving both the physical and algorithmic components of the platform, ultimately aiming toward a more adaptive and capable household assistant.

7 Declaration of Work

Zexin Lin: Simulation and real-world task actuation.

Chang Hong: Mechanism design and deployment.

Yebin Zhong: Control system algorithm development and testing.

These authors contributed to the work equally and should be regarded as co-first authors.

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