Design of a Container Mechanism for Trash Collection on Quadruped Robots

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***Abstract*—This paper presents the design of a novel container mechanism, tailored for autonomous robotic trash collection, specifically designed for mounting on quadruped robots. The commercial AlienGo and Z1 Unitree robotic arm, along with the container developed in this project, have been integrated to form a robotic system capable of effectively navigating and cleaning environments characterized by rough terrain, such as beaches, stairs, and rocks. The proposed container enables seamless interfacing with the robotic arm, facilitating efficient trash storage and autonomous unloading operations. Furthermore, the container has been engineered to be lightweight, complying with the quadruped's payload constraints, yet it possesses robustness against the potential damage encountered in real-world operations. The design process started from scratch, with multiple conceptual designs being evaluated. Subsequently, comprehensive mechanical design and simulations were conducted to develop a mechanism that meets the project's requirements and objectives efficiently. The construction and real-world testing of the mechanism successfully confirmed its functionality and integration within the robotic system. The final container mechanism proposed in this paper represents an innovative subsystem, equipped with essential features for integration with the quadruped robot and the robotic arm.**

***Keywords*—Robotic Mechanism Design, Autonomous Trash Collection, Legged Robot, Mechanical Design**

I. Introduction

Environmental pollution, particularly with plastic waste, poses significant ecological and health risks. Studies show that vast amounts of plastic debris are found in the world's oceans and coastlines, affecting marine life and water quality [1]. The need for effective waste management systems is critical, as highlighted by Ryan et al., who noted the prevalence of plastic bottles on beaches and their sources from urban centers [2]. The adoption of advanced robotics in addressing these issues is therefore not just beneficial but necessary for sustainable environmental management.

Current robotic solutions, such as those developed by Nagayo et al. and Chang et al., primarily employ wheeled robots for trash collection [3] [4]. However, these systems often struggle on uneven terrain, limiting their effectiveness in certain environments. This highlights a significant gap in the existing technology: a lack of specialized container mechanisms that are adaptable to both the unique movement capabilities of quadruped robots and the operational requirements of autonomous trash collection and unloading.

To bridge this gap, this study introduces a container mechanism designed to integrate seamlessly with both the robotic arm and the quadruped robot, ensuring effective operation across various terrains. The design addresses several key requirements: it is lightweight to comply with the payload constraints of quadruped robots; it is robust enough to withstand environmental stressors such as vibrations and impacts; and it features autonomous unloading capabilities that enhance operational efficiency.

The innovative aspect of this project lies in its approach to the integration of mechanism design principles with the dynamic capabilities of legged robots. Unlike previous studies that have not specifically focused on container mechanisms for legged robots [5] [6], this paper proposes a design that is not only functional but also adaptive to the needs of autonomous robotic systems navigating difficult terrains.

II. Literature Review

Recent advancements in robotics have significantly contributed to the development of automated solutions for environmental challenges, including trash collection. Several research efforts have demonstrated innovative approaches to enhance the efficiency and functionality of these robotic systems. For instance, Kulshreshtha et al. [6] proposed an innovative mechanical design using the Rocker-bogie mechanism for resilient Trash-Collecting Robots, which is mounted on a wheeled robot and moves towards the detected trash, and picks it up.

A notable approach in autonomous systems is the integration of robotic arms with mobile platforms to enhance operational versatility. Liu et al. introduced a garbage classification system integrated with a mobile manipulator, utilizing a Robotnik SUMMIT-XL STEEL mobile platform (3-Degrees of Freedom (DoFs)), and a Franka Emika Panda robotic arm (7-DoFs) to collect the trash on flat ground [5]. Similarly, Mondal et al. [7] implemented a garbage management system that combines a robotic arm with a movable chassis, operated remotely for safer waste handling.

Despite these advancements, there remains a significant gap in the specific area of design of a mechanism for the trash container to be integrated with a quadruped robot with a robotic arm. Most existing designs focus on wheeled or static robotic platforms, which do not adequately address the challenges posed by uneven terrains encountered by quadruped robots. The design also considers the payload constraints and operational dynamics specific to legged robots, distinguishing it from other solutions that primarily focus on wheeled robots [4] [8]. The need for a specialized container that not only supports the operational dynamics of legged robots but also integrates seamlessly with robotic arms for effective trash collection and unloading is still unmet in current literature.

III. Methodology

The development of an autonomous trash collection system for quadruped robots involves a series of systematic steps designed to address the unique challenges of waste management in rough terrains. This section outlines the methodology employed to design, develop, and evaluate the container mechanism that integrates with a quadruped robot and a robotic arm. The methodological approach is segmented into four main phases: 1-System conceptualization and requirements definition 2- Conceptual design and selection 3- Detailed mechanical engineering design and simulation 4- Construction and real-world tests and validation.

A. Objectives and Project Requirements

The project started with the establishment of clear objectives and detailed project requirements. The primary goal was to create a robotic system capable of autonomously identifying, collecting, and unloading trash, particularly plastic bottles, in beach environments. The system comprises three main subsystems: (shown in Figure 1)

1) Aliengo Legged Robot: A commercial quadruped robot known for its stability and mobility on rough terrains. It serves as the base platform providing mobility and support for the other subsystems.
2) Z1 Unitree Robotic Arm: A lightweight, six-axis robotic arm used for its precision and flexibility in trash collection tasks.
3) Custom-designed Container: A proposed mechanism integrated into the robot to store collected trash and facilitate autonomous unloading using the robotic arm.

The operational cycle is programmed in a way that the Aliengo robot walks around the beach area, using its mounted camera to detect trash. Once the trash is detected, the Z1 Unitree robotic arm retrieves the trash and places it inside

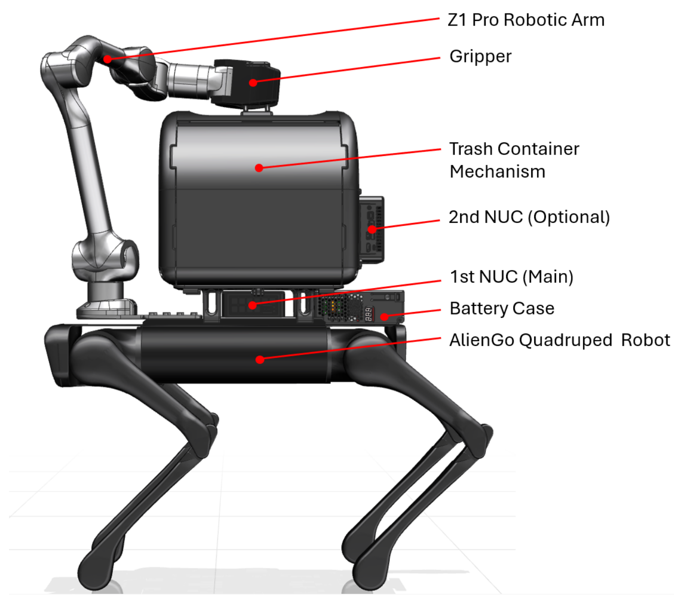


Fig. 1: *This image showcases a comprehensive view of a robotic system mounted on the AlienGo Quadruped Robot. The system includes the Z1 Pro Robotic Arm with an integrated gripper, the trash container, and additional operational components such as Intel NUCs (Next Unit of Computing), and a battery case. Each component is strategically positioned on the legged robot, to balance the center of mass (COM) of the system near the center of the robot, enhancing stability and maneuverability for autonomous navigation and efficient trash collection in diverse environments.*

the onboard container and this process continues until the container is full, at which point the robot navigates to a designated unloading station to dispose of the contents autonomously. This cycle repeats, ensuring thorough cleaning of the beach area. Therefore, the design requirements for the container mechanism included:

- Autonomy: Ability to interface with the robotic arm to autonomously unload trash when full.
- Lightweight Design: Complying with the payload capacity of the Aliengo robot to maintain mobility.
- Robustness: Durability to withstand environmental stressors such as vibrations and mechanical impacts.
- Capacity: Sufficient volume to store up to 20 of 0.5 L plastic bottles, minimizing the frequency of unloading cycles.

B. Conceptional Designs and Down-Selecting

The design phase started with a brainstorming session, leading to the development of five distinct conceptual designs (Figure 2) and the initial CAD models have been created for each design to simulate the movements of the mechanisms. Each design presents its own set of strengths and weaknesses, making it essential to thoroughly assess each one to determine which best meets the project's goals.

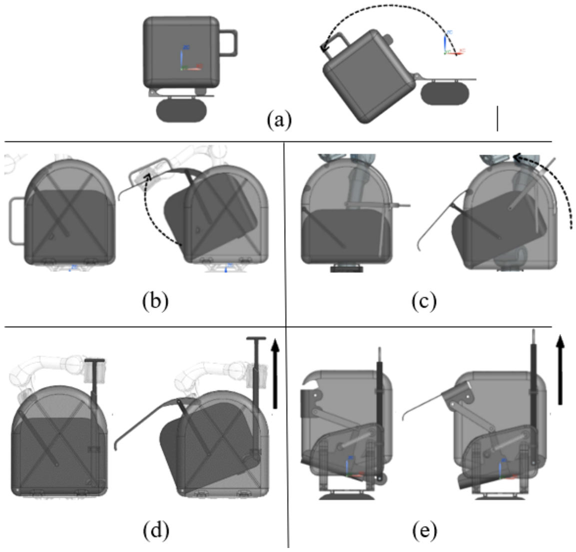


Fig. 2: *Showcase of five conceptual designs, each distinguished by its unique mechanism. These designs have been developed to address specific requirements and challenges, and each one has its own advantages and disadvantages. The required trajectory for the gripper is also presented by an arrow in each mechanism. The linear trajectories are shown by "solid lines" and the unilinear trajectories by "dotted lines".*

Evaluation and Selection Process:
The selection process evaluated these designs against a set of criteria outlined in Table 1 to ensure alignment with the project objectives and meet the established requirements. After a thorough comparison of all designs against these criteria, Mechanism D emerged as the most suitable choice. This mechanism has been selected to advance to the subsequent stages of development.

C. Mechanical Engineering Design

Detailed Cad Design:
The mechanical engineering design phase involved the creation of a comprehensive CAD model for the chosen mechanism (Fig. 3), utilizing the CAD software Siemens NX. This phase was marked by the consideration of various critical factors to ensure the optimal design outcome. These factors include:

- Structural Integrity: Ensuring the structural robustness of the mechanism to withstand operational stresses while operating.
- Ease of Assembly: Simplifying the assembly process to facilitate easy construction and maintenance.
- Space Optimization: Optimizing the design to make efficient use of available space.
- Cost-Efficiency and Lightweight Design: Achieving a design that is both cost-effective and lightweight.

The finalized design resulted in a container that has a weight of 2.6 kilograms and external dimensions specified as 310 mm in length (x), 360 mm in width (y), and 445.5 mm in height (z).

Table 1: Selection criteria of the five conceptual mechanisms

No.	Criteria	Description
1	Vibration Compensation	Minimal vibration during robot movement
2	Complexity	A mechanism that is both simple and effective
3	Volume Efficiency	Optimizing the amount of trash the container can hold relative to its size
4	Weight	Keeping the container lightweight
5	Robustness	Resistant to damage and impacts likely encountered in real-world scenarios
6	Manufacturability	Easy and cost-effective to manufacture
7	Appearance	Attractive design that complements the robot
9	Force Efficiency	Optimizing the mechanism's force efficiency through the mechanism
10	Gripper Motion range	Reducing and simplifying the required movement range of the gripper
11	Gripper Motion Type	Preference for a linear over a nonlinear (round) gripper trajectory

Mechanism operational overview:
The operation begins with a robotic arm picking up trash from the ground, which is then dropped into the container through an entry located at the top. For the unloading process, as displayed in Fig. 4, the robotic arm autonomously performs the task using an efficient method: the robotic arm engages with the container's handle (Part 4b – Fig. 3) and lifts it in a straight, upward motion. To fully open the container door (Part 3 – Fig. 3), the handle is raised by 114 mm. This lifting force is transmitted to the internal basket (Part 2 – Fig. 3), causing it to rotate by 26 degrees. The force moves also through the two links (Part 6 – Fig. 3) to of the container door, opening it by 48 degree. These actions occur simultaneously to ensure efficient unloading of the content. After the content is discharged, the mechanism autonomously returns to its original configuration, utilizing gravity to reset the system.

Motion Simulations:
To achieve an optimally designed mechanism, both in terms of dynamic forces and geometric configuration, comprehensive motion simulations were conducted using the software Siemens NX (Fig. 5). These simulations were critical in determining the mechanism's behavior under various operational conditions, allowing for the identification of the maximum forces that the mechanism is subjected to. The simulations were initiated by applying a vertical displacement of 114 mm to the handle over a duration of one second.

The output from these simulations is a detailed plot that quantifies the force exerted on each joint. The insights gained from these motion simulations provided essential parameters

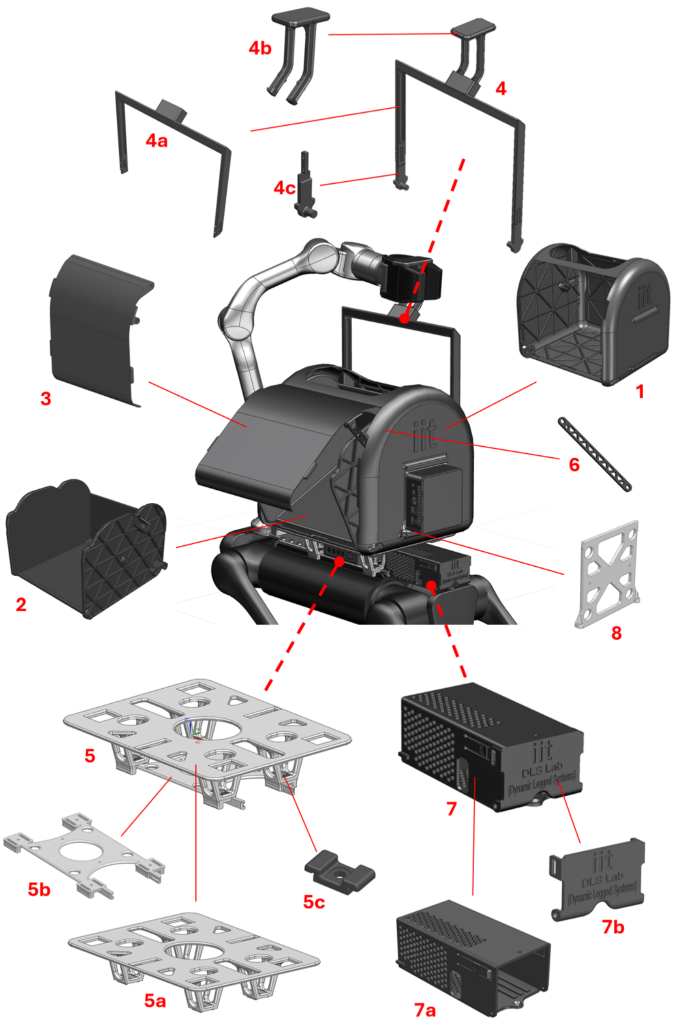


Fig. 3: *This image presents a detailed mechanical engineering CAD design and the assembly of the selected mechanism, including part numbers.*

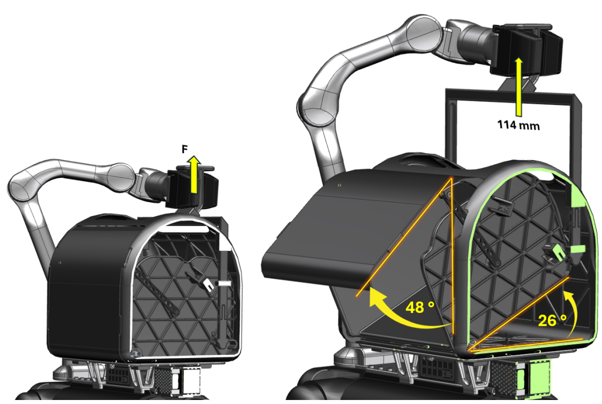


Fig. 4: *An overview of the mechanism's operation is provided in this figure. A vertical displacement of 114 mm is applied by a robotic arm to part No. 6 – fig.3, resulting in the rotation of the trash basket (part No. 2 – Fig. 3) by 26 degrees and the door (part No. 3 – Fig. 3) by 48 degrees. This sequence of operations ensures that trash can be unloaded autonomously.*

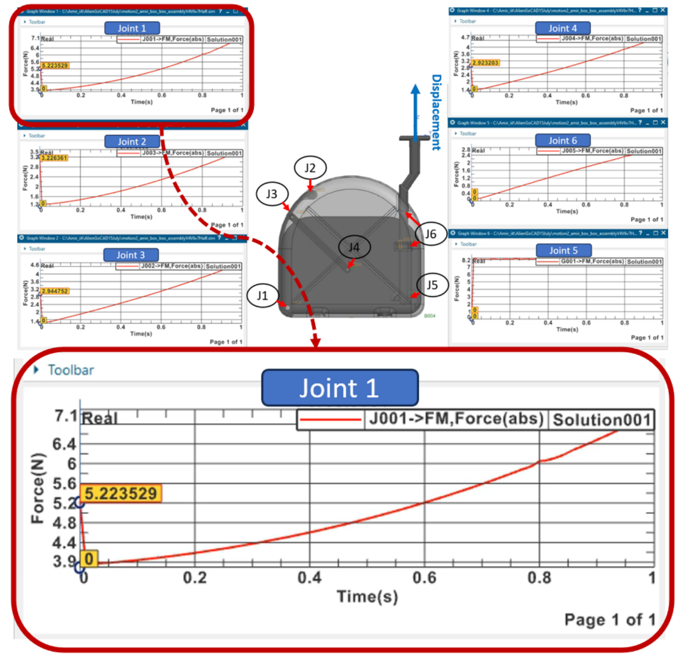


Fig. 5: *This figure presents motion simulations performed on the selected mechanism. Output plots from the motion simulation of the mechanism's six joints are shown. The simulation applies a specific displacement of 114 mm to the handle (identified as part No. 4b – Fig. 3) as an experimental input and plots the resultant force (in Newtons) exerted on each joint over time (seconds)*

that were subsequently used as input data for Finite Element Method (FEM) simulations.

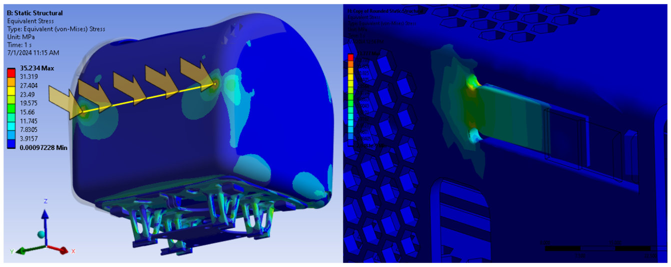
Finite Element Simulations:

Finite Element simulations were conducted to ensure the design's durability and reliability under various conditions (Fig. 6). FEM plays a pivotal role in this project, enabling the execution of time-dependent simulations that are crucial for understanding the mechanism's response to specific stress conditions, such as when subjected to varying degrees of deformation across different areas. These simulations help in predicting how deformations in one part of the mechanism may influence the behavior of other parts, facilitating a comprehensive analysis of the mechanism's structural resilience and functional reliability under real-world conditions.

D. Special Features of the Container

We developed features to enhance the operational efficacy of the system and ensure reliability and ease of maintenance. These solutions aim to effectively address the practical challenges encountered in real-world environments:

- Autonomous Trash Unloading: The container mechanism is equipped with an automated unloading feature that enables the robotic arm to independently handle trash disposal. This capability allows the robotic system to complete the entire trash collection cycle autonomously.



(a) (b)

Fig. 6: *This figure displays Finite Element Method (FEM) simulations for the chosen mechanism. Two examples of FEM simulations are depicted: (a) demonstrates a simulation where a distributed displacement of a 10 mm in the +X direction is applied on part No. 1 - Fig. 3, with the resulting deformations on part No.5 – Fig. 3 being closely examined. This ensures that the maximum structural stress does not exceed the maximum stress-strain capacity of ABS material. (b) shows a simulation investigating the deformation of the battery case (part No. 7 – Fig. 3) when force is applied to its sides with fingers to facilitate the opening of the battery case door. This simulation verifies the functionality of the battery case's open and close operations.*

- Robustness Against Impact Forces: To enhance the mechanism's durability, especially in the face of collisions, a carefully designed breaking point has been incorporated. This includes a special low-cost washer (part No. 5.c – Fig. 3) that is engineered to break under excessive force, thereby absorbing impact and preventing potential damage to more critical and costly parts of the mechanism. This intelligent feature ensures that in the event of a crash, the washer can be easily replaced.

- Quick and Easy Installation: The container has been crafted with numerous user-friendly characteristics, significantly simplifying the installation process on the robot. Efforts have been made to reduce the use of screws, choosing instead for quick-connect attachments that accelerate assembly. Notably, attaching the container to the mount (part No. 5 – Fig. 3) requires no screws, exemplifying the design's emphasis on efficiency.

- Gripper Handle Customization: The mechanism's gripper handle (part No. 4b – Fig. 3) is designed for easy adaptation to different arm grippers. This adaptability feature ensures that the handle can be quickly and effortlessly changed by the operator, promoting versatility across multiple applications. Additionally, to enhance the transportability of the container and minimize potential damage during transit, the handle should be detached. It can then be reattached upon reaching the destination.

- Lightweight and Robust Design: The mechanism's design incorporates lightweighting principles to achieve an optimal balance between weight reduction and structural integrity. Through strategic design choices, including the use of structural ribs, the mechanism remains both lightweight and sturdy.

- Vibrations Compensation: Given the significant vibrations produced by legged robots during locomotion, the mechanism includes a feature to firmly hold the basket (part No. 2 – Fig. 3) inside the container body (part No. 1 – Fig. 3). By incorporating two strategically placed magnets, the basket is securely attached to the container's body, minimizing vibration-induced displacement, and ensuring stable operation.

- Easy to Manufacture and Low Cost: The mechanism's design prioritizes manufacturability and cost-efficiency, primarily achieved through the use of 3D printing technology. This manufacturing approach allows for complex parts to be produced with minimal waste and without the need for expensive tooling, significantly reducing production costs. Additionally, the decision to utilize standard commercial components, especially for the joints, further contributes to the mechanism's cost-efficiency. These components are readily available from local online shops, ensuring not only ease of assembly and replacement but also keeping the overall manufacturing costs low.

- Providing Short and Linear Gripper Trajectory for the arm: The design incorporates a short and linear trajectory for the arm's gripper. This simplification of the gripper's motion not only eases the programming and control of the robotic arm but also enhances precision and overall system performance.

IV. Construction, Tests, and Validation

Construction and Assembly:

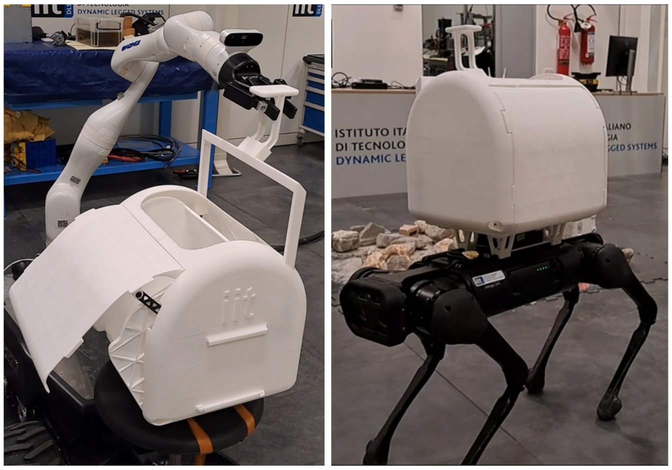
The container was constructed using Acrylonitrile Butadiene Styrene (ABS) due to its lightweight and durable properties, fabricated through Selective Laser Sintering (SLS), which excels in creating complex geometries without supporting structures. After printing, critical areas of the parts, especially joints, were drilled to reduce friction, ensure precise tolerances, and enhance the fluidity of movement. Then the final assembly of the components was carried out to ensure that all parts fit perfectly, followed by quality assurance tests to ensure that every component functioned as expected within the robotic system.

Tests and Validation:

The testing and validation phase was designed to ensure the container's seamless integration and functionality within the robotic system. This phase involved two essential tests, as visualized in Fig. 3.

The first test examined the interaction between the container and the robotic arm. During this procedure, the arm robot was tasked with picking up sample trash and depositing it into the container. Following this, the robotic arm engaged with the container's handle and lifted it to activate the unloading mechanism. This test successfully verified that the robotic arm could engage with the container to perform both loading and unloading operations.

The second test focused on the integration of the container with the quadruped robot. For this test, the container, along with essential components like the NUC and the battery case, was mounted on the robot. The quadruped robot then performed various mobility actions, including walking at different



(a) (b)

Fig. 7: Real-world evaluation of the container integration with the robotic system. (a) This image showcases the container's functionality test with the robotic arm, where the robotic arm is programmed to pick up trash, place it into the container, and perform the unloading processes by lifting the handle. (b) The second image illustrates the container mounted on the quadruped robot, illustrating the robot's operational testing through various movements such as walking and performing torso rotations to evaluate the container's vibration compensation and seamless integration in dynamic scenarios.

speeds and executing torso rotations, to assess the container's stability and performance under dynamic conditions. The results were promising; no unusual vibrations were detected and all components remained stable throughout the testing process. The positive outcomes from these tests confirmed that the container mechanism was well-integrated within the robotic system, interacting flawlessly with both the robotic arm and the quadruped robot, in real-world environmental challenges. Despite using the Kinova Arm due to the unavailability of the Z1 Unitree robotic arm, plans are set for full integration with all components once the Z1 arm is acquired.

V. Conclusion

This project has successfully developed a novel mechanism for trash collection on quadruped robots, making a significant contribution to the field of EcoRobotics. Starting from scratch, by leveraging advanced design and simulation techniques, we have created a solution that enhances the efficiency and adaptability of robotic systems in handling complex terrains and tasks. The introduction of innovative features such as autonomous trash unloading, impact resistance, user-friendly installation, and vibration compensation demonstrates our commitment to addressing practical challenges in this robotic trash collection project. The successful construction and subsequent real-world testing have confirmed the functionality and robust integration of the container within the robotic system. This project not only extends the operational capabilities of quadruped robots but also sets a foundation for future advancements in robotic environmental conservation. Through continuous improvement and application of the findings, this work aims to inspire further exploration and development in the intersection of robotics and sustainability.

VI. Acknowledgment

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