Design Review Report 1

Integrating Control Systems with Boston Dynamics' Spot Robot

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Introduction

Nuclear waste sites, such as the one at Hanford in Washington State, have reached their shelf life and started to leak leading to land and groundwater contamination—remedial effort involved removing nuclear waste from the tanks at the sites and transferring them into safer containers. The Department of Energy commissioned LANL to find a solution for effective removal. Our senior design project, sponsored by LANL, addresses one aspect of this problem and involves designing an advanced robotic solution for nuclear waste removal.

Located in Washington, the Hanford cleanup is currently underway which is the attempt to clean and repair nuclear storage sites. Starting in the 1940s, nuclear weapons were being produced and with that, a large amount of radioactive and chemical wastes were created. This led to large amounts of land and groundwater contamination by nuclear waste. To remedy this, efforts have begun to remove waste from the tanks and relocate it into safer containers.

Currently, the removal process involves "slurrying" the tanks. To achieve this, the tanks are filled with water and drained to remove all of the radioactive waste. This process is inefficient because it requires a lot of water and is very expensive. Our team has been asked to create a 6-degree-of-freedom robotic arm attached to a quadruped robot to clean waste inside the storage tanks. We are working with Dr. Mascarenas from Los Alamos National Labs to achieve our solution. He has provided us with his research on robotic arms and research articles covering the scope of the Hanford cleanup. Additional problems for the nuclear waste removal process have arisen because this waste is stuck to the walls of the tank. This solid waste is a key factor for us to consider when designing a robotic arm. We need to consider creating an arm that is robust enough to withstand forces from cleaning up solid waste.

Our sponsors have identified the quadruped "Spot" robot from Boston Dynamics as the robotic platform on which the arm will be mounted. Our team has divided this project into three areas of research: Arm tool attachments and storage, the dynamic behavior of the arm, and the electrical behavior of the arm. My research area of focus is the electrical behavior of the control arm. To gain a better understanding of the background of the project, I focused on the capabilities of the Boston Dynamics "Spot" robot for the first part of my research.

Background

Boston Dynamics' Spot is a quadruped mobile robot that can be used for a variety of tasks from data collection to incident response. Spot is a four-legged robot that can navigate diverse terrain from flat to hazardous. It can be deployed for manual operations, autonomous missions, and can operate without human intervention. Spot has a payload capacity of 14kg, robust API, and comprehensive documentation so it can be tailored to a variety of applications [3]. This makes Spot an ideal vessel to enter the waste tanks and carry the robotic arm to remove nuclear waste. Spot has navigational capability which is enabled by LIDAR technology; this technology allows Spot to map surroundings quickly and accurately [1]. Lidar technology, light detection and ranging, is a three-dimensional laser measurement that allows the surrounding environment to be mapped quickly and accurately. Spot can maneuver unknown, unstructured, or antagonistic environments and can collect various types of data, such as visible images, 3D laser scans, or thermal images. This makes Spot an ideal robot to send into the hazardous environments of the nuclear waste tanks. Spot achieves this through five stereo cameras and greyscale image sensors embedded into the body: two on the front, one on each side, and one on the back. These cameras utilize a textured light projector and project on the ground to indicate stable ground for the robot to place its feet. Spot is programmed to perceive anything above 30 cm in height as an obstacle and walk around it to prevent tipping off balance [3]. Spot has utilized these capabilities in partnership with industries such as construction to carry out dangerous tasks and navigate the terrain of factories and construction sites [3]. This creates efficiency in the work site as well as prevents accidents from occurring.

Control systems and motors for the robotic arm attachment on Spot are critical for the desired functionality of cleaning up nuclear waste. Control systems and motors form the backbone of functionality and precision for robotics. Control systems allow for precise coordination of the arm's movements, ensuring accuracy in tasks. To create movement in the robotic arm, a control system will need to be utilized. Control systems are crucial for accurately moving the arm to desired positions, maintaining stability, and ensuring precise and smooth operation. The role of the control system is to calculate the joint motor commands that will create the required changes in the robot's configuration. This process involves solving the inverse kinematics equation, which takes into account the geometry of the arm, its joint limits, and any external forces acting on the system. The control system must continuously adjust motor commands to ensure that the arm responds correctly to both planned and unplanned changes in its environment. This dynamic recalculation is critical for tasks involving real-time adjustments, where precise positioning is essential to the robot's performance.

Inverse kinematics is a fundamental concept in robotics, focusing on determining the necessary joint parameters to achieve a desired position and orientation of the robot's end effector Unlike forward kinematics, where the end effector's position is derived from known joint parameters, inverse kinematics works in reverse. It calculates the joint angles and positions required to bring the end effector to a specific location in space. The complexity of solving inverse kinematics increases with the number of joints, especially in systems with multiple degrees of freedom, such as robotic arms, where multiple joint configurations may lead to the same end effector position.

Proportional-integral-derivative controllers are used for the most basic joint control operations. They function by reading a sensor, computing the desired actuator output, and summing three input responses to compute the output [2].

Model predictive control (MPC) is a sophisticated control strategy that employs a system model to forecast future behavior over a specified time horizon [4]. However, in tasks such as grinding or welding, which involve physical interaction between the robot and its environment, the implementation of MPC becomes more challenging. This is primarily due to the need for the robot to anticipate the resulting forces and torques. As a result, MPC is not suitable for our solution, as the interaction with unknown materials would render the prediction of forces impractical.

Additionally, motors provide the essential power and motion required for smooth operation, enabling movement at the robot's joints. Robots are frequently deployed in hazardous and high-stakes environments to perform tasks resembling human actions, making it imperative that the motors are precisely matched to these demanding requirements.

Problem

Solution Neutral Problem Statement (SNPS)

There should be such a technology that can efficiently remove radioactive waste without causing damage to the environment or pre-existing containment systems.

Mission Statement

The chart below depicts key aspects we will consider when designing our mission statement.

Mission Statement: LANL Power Tool Arm Attachment for a Quadruped Spot Robot	
Product Description	Design a Power Tool Arm Attachment with cleaning capabilities
Key Business or Humanitarian Goals	• Effectively clean nuclear waste from Nuclear Waste Tanks to prevent contamination of local environments and populations • Successfully Prototyped and Fabricate Robotic arm within 8 months
Primary	Department of Energy

Market	
Secondary Market	• US Government • US Military • Nuclear Energy
Assumptions	We can assume: • The robot can withstand harsh radioactive environments • The robot can handle large amounts of force without tipping over • The robot can handle large amounts of force without damaging the tank wall • Visibility will allow for sensors to determine if plutonium is being removed • We assume the material is a hard tar heel substance
Stakeholders	• Washington Citizens • National Research Labs • Department of Energy
Avenues for Creative Design	• Cleaning attachments • Design of arm movement/control • Semi-Autonomous
Scope Limitations	• Resources • 4 group members • 8 months to work • No Boston Dynamics robot dog to experiment with • Size limits • Force limits to protect the tank • Operation limits

The problem is really about keeping the citizens of Hanford Washington safe by cleaning up the hazardous nuclear waste being stored in bins. Hanford has produced two-thirds of the plutonium used in US nuclear weapons stockpiles. The implicit expectations and desires of our project involve human-like dexterity to achieve six degrees of freedom. Haptic feedback and remote control allow the robotic arm to be controlled from a distance with real-time sensory information. Operational efficiency in confined spaces is essential for our project to operate within the confined spaces of the waste containers. Tool compatibility ensures seamless integration with cleaning equipment. Passive force control is crucial for allowing the robotic arm to interact with the tank walls without causing damage and creating more radiation leaks. Finally, minimal human intervention is needed because the robot will be operating in a highly radioactive and dangerous environment. Currently, we have not explored all avenues of possible solutions. The customer needs and constraints seem appropriate for the proposed solution, but we cannot be certain until all possible solutions are researched further. One constraint that may not be appropriate is a robotic arm with seven degrees of freedom. We might be able to create a functional solution that requires less degrees of freedom. Three main avenues we have identified for creative design and inventive problem solving are the tool exchange system, force actuator, and the feedback system on the end of the robot. These are all aspects that can contribute to protecting the wall of the container the waste is stored in. We need inventive problem-solving to remove waste from the wall without damaging the wall and allowing even more radiation to seep through. One of the main limitations of the scope of our robot is that the payload must be able to attach to aluminum payload rails. These rails can accept T-slot nuts such as Misumi HNTR5-5. Because we are using this frame to attach our payload, we must ensure that the mounting screws do not project more than 6.3 mm below the top surface of the mounting rail and that the T-slot nuts are fully supported along each edge.

The product must possess 6 degrees of freedom for high flexibility and dexterity. It should be able to easily mount on the Spot robot through attachment to the aluminum payload rails. Our design should create a seamless integration between the Spot robot and our robotic arm. The design must support multiple attachments, such as grinders, wire wheels, drills, vibratory cutters, and sanders, to perform various tasks to clean up waste. Passive force control is essential for safe and precise operation in the sensitive environments of the tanks. Additionally, the product must adhere to the specific parameters and dimensions required for compatibility with the Spot robot.

Our product must ensure it does not damage the container walls during cleaning tasks while being compact enough to fit on the Spot robot using the aluminum payload rails. Additionally, the force and torque generated by the arm attachment must not cause the Spot robot to tip over during operation.

Given the open-ended nature of the project, certain design aspects cannot be quantified at this stage. One inherent limitation is the use of the Boston Dynamics Spot robot as the platform for our robotic arm, despite the possibility that other quadruped robots may be better suited for navigating the hazardous terrain within storage tanks.

The design task involves several technical challenges, including the need for the robot to operate semi-autonomously via remote control, requiring a complex control system not typically covered in mechanical engineering coursework. Another concern is the potential impact of radioactive materials on the arm and robot components, raising issues related to durability and safety. There is not a lot of research available on the effects of nuclear waste on the storage tanks which means our solution needs to be carefully thought out. The robot's cleaning capability is also restricted by the tank depth, limiting access to about 5 feet from the ground. Moreover, the system is designed to handle tanks with minimal liquid or sludge plutonium, focusing on removing tar-like substances adhered to the walls. Limited visibility during operation further complicates control, highlighting the need for an intuitive design and user-friendly control system to enhance maneuverability and effectiveness.

Conclusions

This project aims to ensure the safety of Hanford, Washington by addressing the cleanup of hazardous nuclear waste. Our robotic arm must achieve human-like dexterity to perform intricate tasks. This arm must integrate seamlessly with the Spot robot by adhering to specific dimensions and payload constraints. Our project faces the challenges of needing a sophisticated control system to navigate the tank's depth and visibility. Boston Dynamics' Spot is a versatile quadruped robot capable of navigating various terrains, from flat surfaces to hazardous environments. To effectively integrate a robotic arm with Spot, understanding control systems and motors is crucial. Control systems ensure accurate coordination and smooth operation of the arm.

References/Citations

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