Project Name: Power Tool Arm Attachment for a Quadruped Spot Robot

Sponsor: Los Alamos National Labs

Section 902

Power Tool Attachments for Quadruped Robotic Arm

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"In my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work"

Jade Waldron

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Glossary

Term	Definition
Ah	Amp-hour
DOE	Department of Energy
EPA	Environmental Protection Agency
LANL	Los Alamos National Laboratory
OPM	Oscillations Per Minute
oz	ounces
V	Volt

Introduction

The Hanford site in Washington State, once a critical location for plutonium production during the Cold War, is now one of the most challenging nuclear waste cleanups in the U.S. Over its decades of operation, Hanford produced more than 56 million gallons of radioactive and hazardous waste, which is stored in aging underground tanks [1]. Originally designed with a 25-year lifespan, many of these tanks have outlived their expected service, with over 60 tanks in a deteriorating condition. This situation presents significant risks, as the solidified radioactive waste, often in crystallized-salt form, poses challenges for traditional cleanup methods. As these tanks have exceeded their design life, some have already leaked, posing a risk to the nearby Columbia River. The inefficiencies and high costs of current waste retrieval methods have prompted the DOE and stakeholders to seek more effective solutions.

In response to this critical issue, Los Alamos National Laboratory (LANL) has tasked our senior design team with developing an innovative robotic solution. Our Capstone team consists of four members: Izzy Baumler, Dalton Boeckmann, Morgan Gullo, and myself. Our team is designing a 6-degree-of-freedom (DoF) robotic arm, which will be mounted on a quadruped robot, to perform cleaning operations inside the Hanford tanks. The main goal of this project is to break up the solidified waste deposits on the walls of the tanks, enabling safer and more efficient removal.

The existing slurry mobilization method, which relies on flushing tanks with liquid to dissolve and extract waste, has proven inadequate for addressing solid waste deposits [2]. But it has difficulties breaking up solid chunks leading to an incomplete removal. The existing waste retrieval methods are proving inadequate for the needs of Hanford's underground tanks. The gaps in existing retrieval technologies create a need to explore new technologies such as Dry Retrieval. Dry Retrieval techniques minimize the use of liquid and focus on breaking down and safely transporting waste for disposal as seen in **Figure 1**. By leveraging technological advancements, we aim to identify solutions that could accelerate the Hanford cleanup.

Figure 1: Proposed Dry Retrieval Schematic [2]

The Hanford Site's deteriorating tanks and restricted access points, often no larger than a foot in diameter, make traditional equipment inadequate for waste retrieval. The high levels of radioactivity inside the tanks also require remotely operated machinery that can withstand radioactive conditions without failure. By leveraging advances in robotics, our project aims to provide a more robust solution for waste retrieval. Under the guidance of Dr. David Mascarenas from LANL, we are working to develop a solution that will mitigate the risks of further environmental contamination while improving the overall efficiency of cleanup efforts.

Background

For this report, I will focus on possible power tool attachments that can be used to clean the sides of nuclear waste tanks. One of the goals for our capstone is to design and build an arm attachment for the Spot robot that can effectively deploy a wide variety of power tools. Our power tool considerations include vibratory cutters, grinders, brushes, sanders, chisel scalers, wire wheels, and drills, each chosen for its unique ability to meet the challenges posed by tank cleaning. It would be ideal if between all of these power tools, we could have a commonality in how they attach to the Spot robot. There are a lot of unanswered questions when it comes to these attachments that we hope to have answers to soon. Some include: How will the spot robot be able to store all of these attachments? How will we incorporate passive force control? Will the arm have enough Degrees of Freedom to enable all of these power tools to work properly? Ultimately, the goal is to incorporate as many attachments in one Quadruped robot as possible. The goal is to find power tools already on the market that can be modified to fit our robotic arm, with weight being a large factor in whether it's feasible. This analysis details the functionality of each power tool attachment.

Vibratory Cutters/Oscillating Tool

Vibratory cutters feature a small blade that is fixed on one end while the other end moves rapidly back and forth in an arcing motion similar to that of a pendulum swing [3]. The combination of vibration and sawing works well for cutting materials like metal, drywall, and wood. It is ideal for light-duty tasks and is rather compact. Top power tool manufacturers for vibratory cutters include DeWalt, Bosch, and Dremel. The three most popular vibratory cutters from the top power tool manufacturers weigh around 3.4 pounds. On average, oscillating multi-tools have a motor power ranging from three to four amps and a speed ranging from 8,000 to 22,000 OPM [3]. Reference **Figure A** in Appendix A to see an oscillating tool comparison.

Angle Grinders

Angle grinders are handheld power tools used for grinding and polishing. Most grinders are electrically powered and are usually offered in a corded or battery-powered model. The disc is the part of the tool that does the grinding and can be replaced when worn. If using an abrasive or diamond wheel, cutting metal is one of the most common uses for an angle grinder. Angle grinders can also utilize cut-off discs, abrasive grinding discs, grinding stones, sanding discs, wire brush wheels, and polishing pads [4]. Angle grinders have large bearings to counter forces generated during cutting as seen in **Figure 2**. Common uses for an angle grinder include: Cutting ceramic tiles, cutting stone, cutting metal, removing paint, removing rust, removing mortar, cleaning metal, cutting and carving wood, and planing tools [5]. In our capstone project, we are interested in smaller angle grinders which typically weigh three to five pounds. Cordless models typically have a speed of 8,000-9,000 RPM [6].

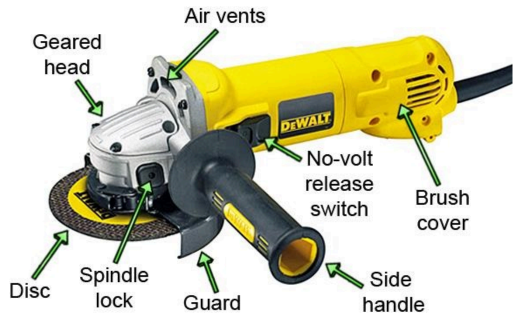

Figure 2: Angle Grinder Schematic [7]

Brushes

A cleaning drill brush is an attachment that fits into a regular drill, allowing the user to harness the drill's power for scrubbing surfaces. These brushes come in a variety of shapes, sizes, and materials. There are several drill brushes on the market ranging from soft nylon bristles to sturdy brushes for tile and grout [8]. For cleaning Plutonium, a hard and stiff brush would be preferred. Drill brushes are most practical for heavy-duty cleaning scenarios such as ovens, grills, and grates that require power. Drill brush attachments provide extra reach and leverage in corners and areas where exerting force with hands alone is difficult. Smaller brushes start at 4 oz whereas larger brushes can be as heavy as 12 oz [9]. Unlike the other attachments mentioned, drill brushes do not have a power supply so the interface to the Spot robot will be unique. Reference **Figure B** in the Appendix for an example of drill brush specifications.

Sanders

A power sander is a handheld or stationary tool used to smooth surfaces by abrasion with sandpaper [10]. Sanders come in various forms depending on the task and material. Usually, sanders are used in woodworking. Power sanders play critical roles in woodworking and construction. They save workers the time of manually sanding surfaces. Additionally, they deliver a level of consistency and smoothness that is difficult to achieve by hand. Power sanders have several components, including a motor, a sanding pad/disc, and often a dust collection system as seen in **Figure 3**. Cordless Orbital Sanders generally weigh between 2 to 4.5 pounds, operate with a battery voltage of about 18 to 20 V, and have varying Amp-hour ratings from around 2.0 Ah to 4.0 Ah [11]. Bosch, DeWalt, and Ryobi have some of the most popular Orbital Sanders on the market right now.

Figure 3: Sander Schematic [12]

Vibration Chisel Scaler:

Vibration Chisel Scalers remove coatings, corrosion, and other accumulated materials [12]. They can also perform splitting, chipping, pointing, and brick raking. Chisel scalers, similar to miniature jackhammers, are ideal for breaking up hard surfaces (Figure 4). Though niche, common models include the VRS-19 Low Vibration Chisel Scaler and the Vibro-Lo Low Vibration Inline Chisel Scaler, typically weighing around seven pounds [12]. They are both pneumatic tools, meaning they are powered by compressed air rather than batteries. This could prove to be difficult to implement with the Spot robot considering we will only have the electrical interface we are provided from the Spot.

Figure 4: Vibration Chisel Scaler Example [12]

Drills

A drill is a power tool that uses a rotating drill bit as seen in **Figure 5**. They are used to create holes in various materials such as wood, plastic, and metal [13]. There are numerous drills available on the market, each designed for various tasks and materials. Drills are commonly used in woodworking, metalworking, construction, machine tool fabrication, construction, and utility projects [14]. An average-sized cordless drill will weigh about 2-3 pounds and provide around 2 amp hours of battery life [15]. Numerous attachments can be attached to drills, however for this section we are interested in creating holes using screw-like attachments.

Figure 5: Drill Schematic [16]

Wire Wheels

Wire wheels are a set of wire bristles mounted on a hub. Wire wheel brushes are ideal for removing rust, paint, weld splatter, dust, debris from surfaces, smoothing rough edges, polishing metal, and blending welds [17]. It is common to mount wire wheels on angle grinders or drills. Wire wheels are useful where aggressive cleaning or material removal is required. As they are an attachment, the spot robot would need to possess an angular momentum appropriate for the wire wheel. Smaller wire wheel brushes often weigh less than 2 pounds [18]. Reference **Figure C** in the Appendix for the average dimensions of a wire wheel.

Commonality of Attachments

In our capstone to develop a robotic arm for the Boston Dynamics Spot robot, establishing a commonality for these attachments is necessary. The diverse tools we plan to use - vibratory cutters, angle grinders, brushes, sanders, vibration chisel scalers, wire wheels, and drills- pose a unique challenge in terms of mounting and compatibility with the robot. Each tool has its requirements for power supply, rotational speed, torque, and weight, all of which must be compatible with a universal attachment system. Quick-Change Tool Systems, commonly used in industrial robotics, can allow for rapid tool swaps through a standard interface. Popular Quick-Change Tool Systems include ATI Industrial Automation and Staubli Robotics which often come with integrated pneumatic, electrical, and data connections [19]. These Industrial robots are much larger and more powerful but show that it is possible to incorporate different mechanisms into one robot.

The integration of various attachments will require an analysis of the forces each tool will exert and require. Tool attachments such as the angle grinder and sander will produce significant lateral forces that could tip over the robot if not properly accounted for. We are looking to incorporate passive force control using a spring to ensure the tools can be used safely inside the nuclear waste tanks. Another consideration is the need for a semi-autonomous tool storage and retrieval system on the spot robot, which would allow the robot to swap tools as required. Research on similar systems, such as robotic surgical tool changers, has emphasized the need for compact, reliable mechanisms that could work in a confined space such as a nuclear waste tank [20].

Problem

Our capstone aims to design and prototype a semi-autonomous Power Tool Arm attachment for a Quadruped Spot robot within eight months. Establishing a Solution Neutral Problem Statement and Mission Statement have helped our group see the end goal and become proactive in thinking of a solution.

Solution Neutral Problem Statement

The solution neutral problem statement (SNPS) outlines the requirements that must be met for the successful completion of the LANL 6 DoF robotic arm. Following a thorough team analysis, the SNPS was developed to define the key requirements necessary for ensuring the project’s success. The SNPS is as follows: 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 team’s mission statement is to design and prototype a semi-autonomous Power Tool Arm Attachment for a quadruped Spot robot within eight months, with cleaning capabilities catered for the removal of nuclear waste from expired tanks. The team's goal is to prevent contamination of local environments, achieve a functional prototype within eight months, and develop a sustainable solution for LANL to undergo hazardous waste management processes. Our mission statement is outlined in detail in **Table 1** in the Appendix**.**

The problem at the Hanford site revolves around safely cleaning nuclear waste tanks, which are heavily contaminated due to past plutonium production for nuclear weapons. With the site being inactive, the focus is on cleaning up hazardous waste and preventing contamination of the Columbia River. The project is expected to produce a robotic arm with human-like movement, remote control capabilities, and compatibility with various power tools. The design will prioritize safety, efficiency, and minimal human intervention in hazardous spaces. The current proposed solution aligns with the initial customer needs and constraints from LANL. However, further research and analysis must be performed to confirm its feasibility, especially since it will be deployed in harsh conditions. There are multiple avenues open for creative design such as the development of a tool exchange system, passive force control system, power tool attachments, feedback system, and arm dexterity. There are also limitations to limiting the scope such as specific payload requirements, attachment to the spot robot, the weight that the arm can sustain with a power tool, and the size of the robotic arm (similar to a human).

Some characteristics that the product must have include: similar DOF/dexterity to a human arm, being easily connectable to the Spot robot, supporting multiple power tool attachments, including passive force control, and including one force sensor. The arm cannot exceed a length that the robot cannot sustain and should not be overly complex. Additionally, quantifiable aspects of the arm include the size constraint, static force analysis values, and the power requirements that are provided by the Spot robot interface. Our team is biased toward using a Boston Dynamics Spot robot and assuming semi-autonomous operation as the most feasible solution as suggested by LANL. Further research is needed to ensure that this design task is appropriately defined for a larger range of potential solutions.

Designing a robotic arm for radioactive environments presents several challenges including: developing a remote-controlled system capable of withstanding radioactive environments, managing limited visibility in the tanks, and ensuring efficient cleaning without compromising the integrity of the container walls. Although our scope is ambitious, the Mission Statement and Solution Neutral Problem Statement guide our team to address the technical, safety, and operational challenges that will arise.

Conclusion

The Hanford site cleanup effort highlights the need for new solutions due to the hazardous waste stored in expired tanks. To address this issue, the Texas A&M engineering capstone team has been tasked by LANL to research, design, and fabricate a 6 DoF arm for a quadruped robot. The research detailed in this report has provided a comprehensive understanding of the types of attachments available for the end effector of the arm. This analysis will allow us to make informed decisions regarding which power tools to utilize if time allows.

Our approach includes incorporating a variety of tools while addressing important factors such as attachment compatibility, passive force control, and tool storage. The design aims to replace current methods such as slurry mobilization to enhance the efficiency of the waste retrieval process. While the proposed solution aligns with LANL's initial requirements, further research and testing will be conducted to confirm the feasibility and ensure it meets the customer's needs. Additionally, we will maintain project momentum through weekly meetings with Dr. Mascarenas. The success of this project could transform the way hazardous environments are managed, ultimately contributing to a safer and cleaner future.

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Appendix

Figure A: Various Oscillating tools [3]

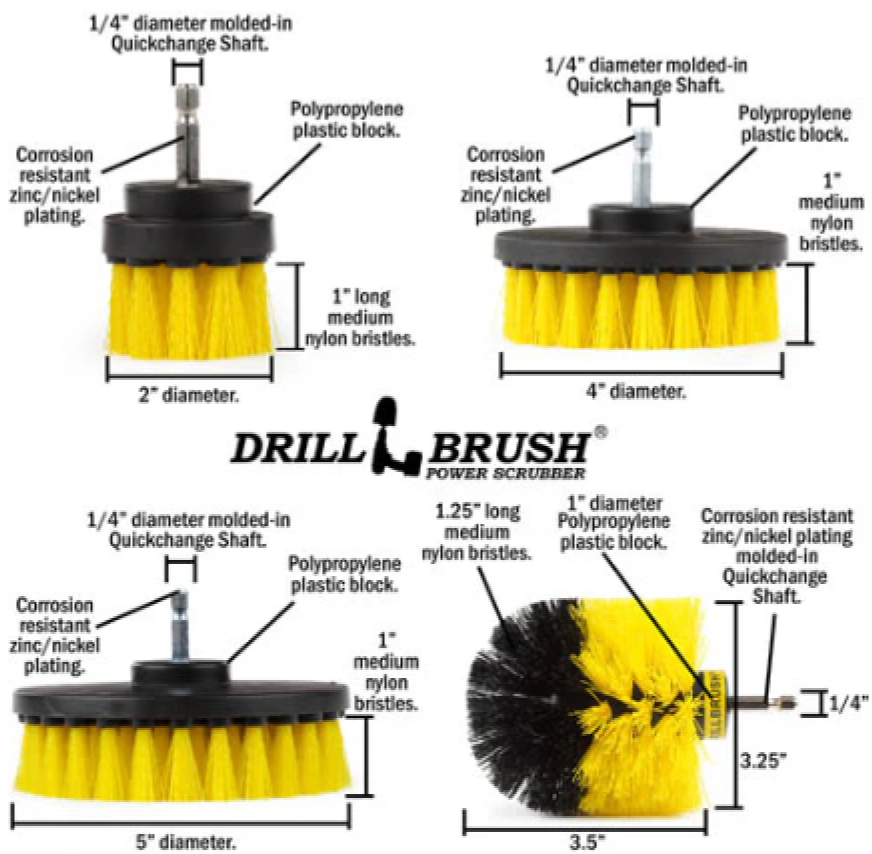

Figure B: Drill Brush Schematic [21]

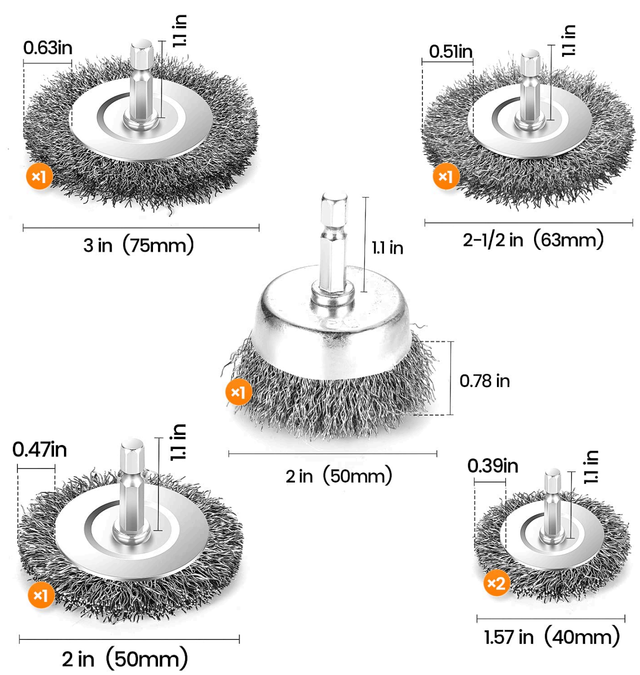

Figure C: Wire Wheel Attachment details [22]

***Table 1*:** 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 Market	Department of Energy
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 robo dog to experiment with ● Size limits ● Force limits to protect the tank ● Operation limits