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# Spot Robot Staffing Augmentation at Los Alamos National Laboratory

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# Abstract

The Process Modeling & Analysis Group (E-2) at Los Alamos National Laboratory has completed a feasibility study and proof-of-concept testing of the Boston Dynamics Spot quadruped robot for use in staff augmentation of tedious, dangerous, or high precision tasks. The immediate focus of this project is to provide systems capable of autonomously performing radiation surveys throughout the laboratory's nuclear facilities. It has progressed to working on the final implementation to perform radiation surveys for nuclear material delivery trucks. Prototype functionality is also being produced to perform object, general area, and facility floor radiation surveys. Augmenting these tasks will allow staff to better focus on core missions and increase productivity throughout the laboratory. Multiple Universities have also been engaged to aid in future Spot implementation research and development work. Spot continues to visit many local schools and science fairs to encourage student interest in Science Technology Engineering and Math disciplines. These events are interactive, allowing students and the public to operate the robots and gain a better understanding of their capabilities. The paper will also outline additional use-cases being pursued including for emergency response and nuclear material inspection. Finally, we will conclude with the path forward at Los Alamos National Laboratory and other potential future work.

# 1. Introduction

Advances in commercialized robotic technology have provided robust mobile platforms capable of performing a wide variety of tasks. Los Alamos National Laboratory is exploring the potential of this technology in augmenting staff for tasks that are dangerous, tedious, or require high precision. At Los Alamos like many nuclear laboratories and facilities, radiation survey measurements are primarily performed by Radiological Controls Technicians (RCTs) and based on discussions some tasks can be tedious and time consuming. For example, radiological inspections of delivery truck beds following shipments of nuclear material often involve RCTs spending hours on their hands and knees performing near contact alpha/beta radiation scans. Supplementing RCTs with robotic equipment would create a safer inspection process by removing staff from potentially contaminated locations and reduce the risk of ergonomic related injuries. This augmentation has the added benefit of simplifying or eliminating undesirable work for the RCTs; improving work satisfaction and increasing their availability to support core laboratory missions.

The Process Modeling & Analysis Group (E-2) has chosen the Spot robot manufactured by Boston Dynamics as the primary robotics platform for our staff augmentation initiatives based on its capabilities, ease of developing custom applications, and off-the-shelf availability. These quadruped systems present a unique capability to provide a "one size fits all" mobile platform that can accomplish a wide variety of tasks using custom designed payloads. In 2022 the team performed a feasibility study and proof-of-concept testing of Spot for use in staff augmentation of tedious, dangerous, or high precision tasks. Radiation tolerance testing was performed as part of this work and is documented in Bloodwood et. al. (2022) [1].

This paper proceeds with a with a review of evaluation and development work performed in 2022 along with findings and lessons learned. Section 2 discusses the current efforts at the laboratory being executed in 2023 to further develop and implement this technology in highly controlled facilities and sites. In Section 3, we describe the Lab's future implementation plans and end state vision we intend to develop for. We then discuss recent STEM outreach events using the Spot robots to encourage STEM disciplines within area schools in Section 4 along with our partnerships with universities to further mature and implement this technology. Finally, we will conclude with the path forward at Los Alamos National Laboratory and other potential future work with implications for the broader INMM community.

## 1.1. Results of 2022 Work

Recently and as described in Bloodwood et. al. (2022) [1], there has been significant interest in the potential for autonomous quadruped robots to provide versatile mobile platforms that can accomplish tasks without significant facility investment and modification. Bellicoso et. al. (2018) describes how a particular quadruped robot performed in robotics competitions including one for an oil & gas industrial inspection and for search and rescue [2]. Their results support the conclusion that legged robots provide an improvement over their wheeled counterparts based on their improved ability to overcome large obstacles such as stairs and their versatility in pointing payloads to accomplish inspections. Delmerico et. al. (2019) also supports this conclusion based an expert review of emergency response stakeholders' opinions on robotic assistance as they tend to perform well in field deployments [3].

Figure 1: Spot robots during radiation testing

In 2021 Los Alamos became intrigued with the potential for quadrupeds to execute tasks at the laboratory. Following an industry review the Spot robot from Boston Dynamics was selected for testing and analysis to determine its potential suitability for operations. When the first robot (locally named "Trinity") was obtained near the start of the 2022 federal financial year there was initially no individual task intended for the robot. It was instead used for pathfinding to determine what, if any, task it could be applied to and provide benefit to the laboratory. The team initially focused on performing demonstrations of the robot's capabilities to interested parties throughout the laboratory and gathered feedback from stakeholders on potential use cases. These demos have proven highly valuable with several possible implementations that otherwise would not have been considered.

Within weeks of its arrival, it became apparent that these leg-based platforms offered significant benefits over our existing wheeled systems that were in development to automate radiological surveys. Spot provided significantly improved mobility, allowing the platform to navigate common facility obstacles such as stairs with ease along with rugged outdoor terrain. The Spot robot also proved to be exceptionally durable, taking several hard falls while traversing highly rugged terrain without damage or degradation in operation. Following the initial radiation testing that demonstrated the robot's tolerance for operation in gamma radiation environments, three additional units were procured including two with manufacturer supplied arms. The existing robotics project pivoted to almost exclusively using Spot robots and in less than a year the new quadruped robots surpassed the capabilities of the legacy platforms.

### 1.2. Lessons Learned From 2022

While the Spot robot proved highly capable throughout the pathfinding work of 2022 there were still lessons learned. The speed at which people have accepted Spot has been highly beneficial but has also presented challenges. A subset of the individuals that have been provided demonstrations and the opportunity to manually operate the robots have mistaken them for docile or toys while they are in fact powerful and potentially dangerous like any other piece of moving machinery. The manufacture is very clear about this, warning personnel to keep a safe distance and respect pinch points at each of the joints.

From the start the team has implemented a safety brief prior to demonstrations stressing the importance of remaining a safe distance from the robots, never attempting to drive one into an individual, and above all not attempting to touch a robot while in operation. Trained operators also always remain near controllers during demonstrations to ensure the safety of users and bystanders. Safety is a core part of any work at Los Alamos which has a strong safety culture but even here there has been instances where a controller needed to be taken from an individual. Due to these findings when working with laboratory employees, demonstrations provided to schools and the public include physical barriers, usually six-foot free standing steel fencing, to help ensure minimum safe operating distances. Multiple operators are also present to provide redundancy to quickly identify and prevent misuse.

## 2. Current 2023 Efforts

For 2023 the team has been pursuing an aggressive set of projects to demonstrate the robot systems' capabilities at a variety of tasks along with getting it ready for a full-scale implementation.

### 2.1. Truck Bed Near Surface Radiation Surveys

The primary push for 2023 is to produce, test, and demonstrate a production ready capability to perform a near surface alpha and beta radiation scan to release delivery trucks following radiological shipments. Currently, this work is staff intensive. It normally requires a group of three or more RCTs spending approximately half a workday on a truck bed scanning the entire surface primarily on their hands and knees. They use a lightweight handheld scintillation detector within 0.6 centimeters of the surface at a speed of approximately 5 centimeters per second. Based on RCT interviews this is a highly undesirable task for multiple reasons including:

- Difficult ergonomic positions that cause discomfort and require frequent breaks.
- Exposure to the environment including high temperatures and direct sun.
- The simple, dull nature of the work is unappealing to highly trained professionals.

The goal of this project is to provide a near fully automated surface scan to:

- Decrease staffing requirements for truck radiation surveys.
- Reduce the potential for ergonomic injuries.
- Improve job satisfaction for RCTs.
- Reduce risk of personnel contamination.
- Increase resources available to directly support core laboratory missions.

This system will only require a single RCT to operate with their only standard responsibility to initiate the scan software, verify the detector source check is acceptable, and monitor progress. Once a significant number of real-world scans have been performed, the hope is that either a standard technician can take over scan execution and/or monitoring duties or that the RCT can start the scan and leave the area for the duration.

Figure 2: "Gadget" in a prototype truck bed scanning configuration

Spot will handle the entire standard scan process and provide real time results to the RCT along with a final report for documentation purposes. It utilizes a custom payload developed by Los Alamos to execute this work that consists primarily of an onboard computer, a LiDAR, an alpha-beta detector with meter, and structure to hold and protect the hardware. The computer runs the Los Alamos produced software to direct the movements of the Spot robot and collect the radiation and location data.

The added LiDAR system provides the ability to locate the robot within the truck to less than 1 cm accuracy to improve scan localization. While the Spot robot may be capable of adequately performing the location services using visual fiducials and odometry, the error in its ability to locate itself in the truck drives a requirement of overlapping of scans to ensure the entire surface is covered by the detector. Minimizing this error and thus overlap proportionally reduces the overall time required to execute a complete scan.

An equivalent scintillator-based detector to currently employed instrumentation by RCTs is used to reduce development and barriers to implementation. It is connected directly under the Spot Arm manipulator and can be removed by the RCT quickly to either use manually as desired or to replace in the event of failure. The detector is connected to a customized benchtop meter which powers the detector and communicates beta and alpha counts to the software. This meter is relatively lightweight and simple to program and communicate with and can support a wide variety of detectors with relatively simple reconfiguration, along with up to 12 channels if desired in the future.

The system starts from a manufacturer provided dock that provides charging to the robot. Once the software is launched by the operator, it begins its pre-scan routines including performing a background alpha/beta radiation count to use as a baseline during the scan. Once all pre-launch checks are met, the system lifts off the dock and locates an adjacent staircase with a specific sign that it uses to access the truck bed. These signs include a visual fiducial and are truck scan method specific as a final verification for the robot and the RCT that the correct scan process was selected. The system will then perform a source check to ensure that the detector and meter are working properly using a depleted uranium source installed on a specifically designed holder attached to the stairs. This source check also exercises the system's probe positioning accuracy providing the user additional assurance that everything is operating properly.

Once all pre-scan activities are successful, the system will climb the staircase and perform an initial LiDAR scan of the truck interior gathering multiple frames from multiple pitch angles to help ensure full coverage. Statistical analysis is performed on the resulting point cloud to remove outliers due to misreads by the LiDAR and to improve on the overall accuracy. Ultimately, a high precision map of the truck floor is generated with relative floor heights and edge locations that is used to build the scanning process.

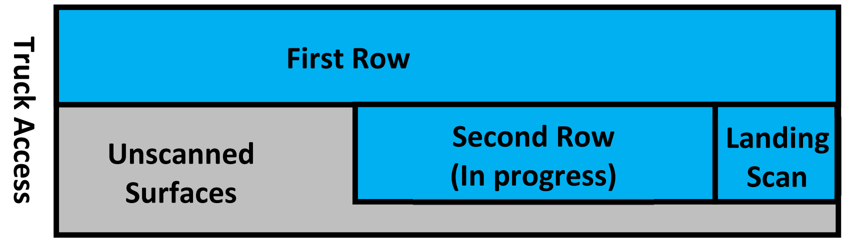


Figure 3: Spot truck bed scanning process

The system precisely positions itself to each scan location and corrects for positioning error using an individual foot location algorithm if needed. In practice, the high precision individual foot locomotion is not often used but helps ensure the robot can maximize the width of each probe scan to minimize overall truck scan durations. The system will use its arm to perform a side to side sweeping motion of the truck floor without contacting the surface to measure radiation levels before moving to the next location. As the system traverses to each location (or needs to exit the truck due to anomalous conditions) all edges and waypoints in the navigation are verified to be within surveyed surfaces to prevent the potential for contaminating the robot's feet. Periodically, the system will reverify its location and yaw relative to the truck walls using the LiDAR and re-localize to the truck.

Throughout the scan, the system continually monitors for anomalies in both system conditions such as battery charge and readings from the radiation detector. If the battery falls below a minimum threshold it will automatically navigate back to its dock to charge, then return to where it left off and restart the scan. The system also follows a standard decision tree equivalent to an RCT if elevated counts of either beta or alpha radiation are detected above background, pausing probe movement to perform longer duration scans to ensure the surface is statistically free of radioactive contamination. If alarm points are still exceeded following these extended scans, the system will automatically exit the truck and notify the RCT of the location of potential contamination.

## 2.2. General Area Radiation Surveys

Another potential application for the Spot robot system is for performing general area radiation surveys. These are performed on a regular basis throughout nuclear facilities for a variety of reasons including:

- Creating radiation dose maps for employees so they better understand locations with elevated radiation readings to reduce radiation dose.
- Identifying changes in radiation dose rates over time to detect potential issues.
- Ensuring newly accessible locations do not exceed acceptable radiation levels for staff to enter to perform maintenance.

While not as tedious as truck surveys, general radiation surveys that involve regular readings from predetermined locations can still be monotonous and time consuming. They also result in radiation exposure to staff that could be avoided through automation. This year the team has been working to demonstrate the feasibility and value of automating this process using a variation of the truck scanning system. It still consists of a Spot robot with a modified Ludlum model 4600 series meter, and a LiDAR system but does not utilize a Spot Arm currently. A 2.5 cm diameter by 2.5 cm long NaI(Tl) based scintillator gamma detector has been incorporated to obtain readings. The demonstration system is also GUI based and allows the user to quickly load a predetermined facility layout with scan locations which the user can add to if desired and the software automatically calculates the shortest navigation path to reach all designated survey locations.

The user posts a starting visual fiducial sign that is included in the facility map so that the robot can localize to the facility, then simply starts the scan process. The system will navigate using the preloaded facility map between locations but also updates obstacles using its LiDAR as it moves throughout the facility. If a location is unreachable due to obstacles it will automatically continue to the next accessible survey point and note the issue for the user. As the system traverses between points, it continually monitors gamma radiation levels and if a pre-defined threshold is exceeded, then it will pause and take a higher fidelity survey. Once complete or the battery level has fallen below what is required to complete the scan, the system will return to the start location and report its results to the user.

## 2.3. Facility Mapping and Data Collection

Facility mapping and data collection are proving highly useful for facility management activities by providing digital twins to document and evaluate buildings and construction projects. This is especially true for nuclear facilities where LiDAR maps can be used in place of onsite inspections, reducing radiation exposure to staff along with the scope required to execute the inspection as it could be performed at a desk instead of onsite. Los Alamos currently performs this work using a variety of methods including high accuracy tripod base metrology systems manually moved throughout a space, and utilizing a backpack-based system where the operator walks the entire facility.

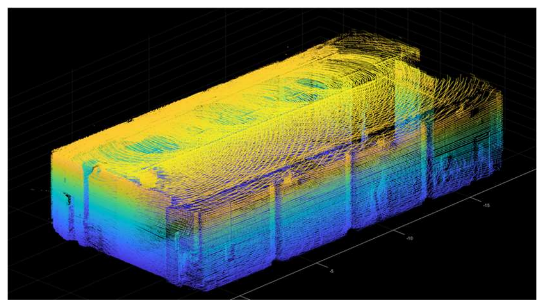

Figure 4: Initial LiDAR scanning results

Automating this process using a Spot robot is expected to reduce the staffing required to execute new inspections, reduce radiation exposure to staff when these inspections are performed in nuclear facilities, and allow for increased scan cadence as it will no longer be subject to staff availability. This process can also be coupled with other desired robotic operations such as the general area radiation scan, allowing it to be performed simultaneously and not increase the number of robotic inspections.

## 2.4. Object Near Surface Radiation Surveys

Nuclear facilities that work with neutron radiation have the potential to activate materials such as equipment or structure. When this material is removed, it requires a detailed radiation survey to ensure that it is not radioactive before free release for disposal or recycling. For large objects, this process can be highly time consuming and tedious. At the Los Alamos Neutron Science Center (LANSCE) particle accelerator, a significant amount of material is currently awaiting radiation surveys for disposition. Space limitations have also resulted in these pieces being stored outdoors, subjecting the RCTs performing release scans to the elements.

The Spot team is currently working on a demonstration to determine the feasibility of performing these scans using a Spot robot-based system. First, it will perform a 360-degree LiDAR scan of the object of interest to identify surfaces. Next, a probe path will be calculated. The robot will perform the scan, applying radiation readings to surfaces within the minimum scan distance. These results will be communicated to the operator so that they can identify what, if any, surfaces were not scanned so that they can perform a reduced surface scan.

For this year, three representative objects that have already been free released have been selected for testing. One object consists of simple, easy to reach rectangles with flat surfaces. Additional unreleased objects will also be manually scanned with the lidar to capture additional geometries to exercise the scanning algorithm.

Initially, an object agnostic approach will be developed and tested to determine its feasibility to operate as a "one size fits all" algorithm. Depending on its level of success, an additional approach that takes advantage of many of the objects' flat, rectangular shapes may also be created to increase the percentage of scanned surface for the object.

# 3. Future State Plans

The team is starting to formulate plans for 2024 and beyond. Based on initial results from the three proof-of-concept projects this year, these are expected to be continued into full scale capabilities with additional enhancements such as the ability to search for sources of radiation during general area scans and gathering additional data such as thermal imaging during facility mapping. Additional proof of concept projects are also being considered that leverage much of the software already being developed.

## 3.1. In Situ Material Interrogation

Another potential use case we plan to explore is for the inspection and survey of material containers within storage locations. Like many other nuclear laboratories, Los Alamos has an extensive collection of nuclear materials stored in containers within vaults. Type, age, and condition varies greatly between containers and the storage locations in general have high radiation dose rates. Some older containers may also have incomplete records that make material identification difficult.

Spot or potentially a higher payload capable robot could be outfitted with columnated instrumentation to attempt to gather in place measurements of individual containers without the need to move them or expose staff to additional radiation dose. While these results would inherently have higher errors than detailed surveys performed outside of the vault, these results will hopfully be capable of identifying gross mismatches between expected and actual materials contained. Detailed inspections of containers could also be performed as part of this work through high resolution photography and laser scans to provide additional information to users that would eventually need to access the material.

## 3.2. Facility Floor Contamination Survey

Converting Spot's truck bed functionality into a facility floor scanning system is expected to provide significant additional benefit without extensive programming or payload design. The truck scan software already provides a GUI and result mapping for the user and would primarily need to be modified to support detailed obstacle detection and an ability for the user to direct scan locations.

## 3.3. Emergency Response Support

Finally, Spot offers a highly mobile platform to inspect potentially hazardous locations without endangering staff. The combination of high-quality video/photography, radiation instrumentation, and ability to quickly incorporate new instrumentation could prove invaluable in the event of an emergency within laboratory facilities, allowing responders to review and evaluate locations prior to entry. Spot has already assisted the laboratory's Emergency Response division when responding to a training exercise with highly positive results. They are also actively training with one of our armed systems for the movement of potentially dangerous waste barrels.

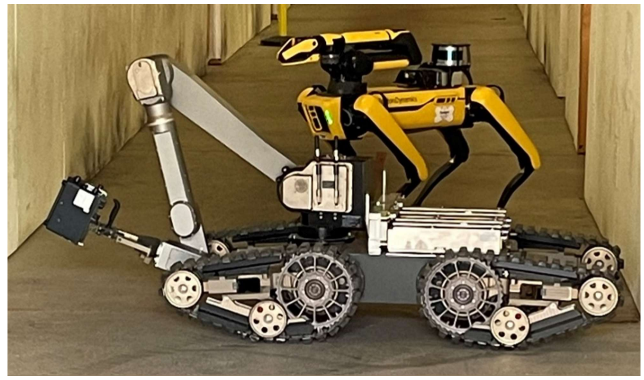


Figure 5: "Gadget" being used for emergency response training.

During a recent parking garage collapse in New York City, United States the local New York Fire Department (NYFD) responded but due to concerns with the structure's integrity pulled emergency services workers away from the site. The NYFD then utilized both a Spot robot and drones to search for victims without putting the first responders in potentially unnecessary risk of harm as reported by Shanahan (2023) [4]. This real-world demonstration of the versatility of the Spot robot has lead the local Los Alamos Fire Department, which also supports the laboratory, to reach out to the team for potential future collaboration.

# 4. Additional Work and Community Outreach

Our current work with Spot has not just benefitted the Lab, but also its surrounding community. Los Alamos National Laboratory supports many initiatives to promote science, technology, engineering, and math (STEM) education in the community. In line with this mission statement, team members conduct regular demonstrations of the Spot robot for the general public and local schools.

As part of these demonstrations, LANL employees provide brief presentations to educate the public about the utilization and versatility of Spot robots for augmenting staff responsibilities at Los Alamos. Everyone is provided an opportunity to operate a Spot robot using a standard controller through a small obstacle course. The team has found that essentially all operators with very minimal training (left stick forward, right stick steer) have been capable of quickly mastering the controls and operating the robot, a testament to the intuitive nature of Spot's manual interface and onboard obstacle avoidance. Amid the feedback received from these demonstrations, participants noted that the opportunity for hands-on involvement with a Spot robot was interactive and generally increased their interest in STEM principles. It is hypothesized that these interactive demonstrations will positively affect student engagement in the classroom and promote interest in other STEM principles. By providing a positive learning experience in STEM principles for young students, we believe that local educational achievement will improve, and the community will continue to develop a skilled pipeline from which the laboratory can draw its workforce.


Figure 6: Spot robot "Trinity" operating in snow during a community outreach event.

## 5. Conclusion

Quadruped robotics are demonstrating their potential to make significant contributions at Los Alamos National Laboratory in staffing augmentation, particularly in simplistic, tedious tasks executed in radiation areas that personnel are happy to hand off. They have proven highly mobile, capable of navigating common place obstacles in our facilities with ease and except for one of our four robots have been highly reliable and durable. Los Alamos looks forward to furthering our robotic augmentations capabilities over the coming years, making the laboratory a safer and more satisfying location to work. Additionally, the Spot robot has been an effective tool for outreach and community engagement through STEM events in the local area. We intend to continue developing this platform for LANL use and for the greater INMM community.

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