Delivering the Nuclear Promise
Top Innovative Practice

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Combining Quadruped Robotics and 3D Radiation Mapping for Radiation Monitoring
2023 Top Innovative Practice Winner[1]

Summary

Utilizing the innovative and cutting edge technology of Boston Dynamics, Dominion Energy has demonstrated the ability to gather radiation mapping data safely and reliably while reducing human effort. Boston Dynamics' Spot[2] quadruped robot virtually eliminates the risk of exposing nuclear power plant staff to radiation, as the technology can be remotely operated while navigating hazardous areas and gathering valuable data. Dominion Energy has demonstrated the value of the Spot robot through its deployment at the Surry Nuclear Power Station throughout 2022.

Innovation

This TIP Award presents the success of the first-of-a-kind (FOAK) combination and application of the Spot quadruped robot developed by Boston Dynamics and the LAMP 3D radiation mapping device developed by Gamma Reality Inc.[3], for radiation mapping at a commercial U.S. nuclear power station. Both technologies are new to the industry. Together they combine the unique capabilities of an agile, remotely operated, robotic platform and dynamic radiation mapping to create something special. With this combination of technologies, Dominion achieved the ability to be fully informed of the radiological conditions in any location without exposing a technician to an unknown radiation field. This combination of technologies was demonstrated at Surry in 2022. They were used to map and scan the fuel building, auxiliary building, Independent Spent Fuel Storage Installation (ISFSI) and areas of Surry's containment including the loop rooms, reactor coolant pump (RCP) motor cubes, and areas around and below the fuel transfer canal during fuel movement. Surry also used these technologies to validate shielding deployments and support work planning for future projects. All these activities were completed with minimal dose to operators and provided data that had not been available prior to using this technology. These tools are now an invaluable asset in Surry's radiological assessment tool kit.

Background

Boston Dynamics is an engineering and robotics design company founded in 1992 as an offshoot from the Massachusetts Institute of Technology. They focus on creating robots with advanced mobility, dexterity, and

[1] Winning entries of from NEI's Top Innovative Practices (TIP) awards are republished as DNP Efficiency Opportunities to ensure the broadest possible dissemination of these operating plant innovations.
[2] https://bostondynamics.com/products/spot
[3] https://www.gammareality.com/lamp

intelligence including the Spot robot. Various iterations of Spot have been in development for almost three decades, ultimately leading to these robots being commercially available in 2020. Dominion Energy purchased its first Spot in 2021 and spent 2022 piloting and demonstrating this technology across the nuclear fleet culminating with deployment in an outage support role during the Fall 2022 refueling outage at Surry.

Spot is a versatile quadruped robotic platform designed to go wherever people go. It can walk, avoid obstacles, climb stairs, navigate over and around various tripping hazards, all while carrying up to 14 kg in payloads on its back. It can also do all of this work across grated flooring and stairs, which was a key capability needed to enable the use of this technology in industrial spaces. It utilizes a custom onboard computer for control, relying on five sensor modules (two in front, one on each side, and one in the back) to assess the area around the robot and uses 12 custom motors to walk, operating for approximately 90 minutes on a full charge.

Spot can be controlled in a teleoperating mode, utilizing a tablet and a self-generated Wi-Fi network. These controls are very simple to learn, and the robot's obstacle avoidance algorithm allows the operator to confidently navigate the robot in teleoperated mode through an industrial workspace. The robot can also be operated in an autonomous mode, utilizing preprogramed routes in combination with spatial recognition to follow a route, step around obstacles impeding the route, and even complete tasks in a different order along the same route if the original sequence is not available due to an obstacle that cannot be overcome. While Dominion has performed a pilot using this capability, integrating autonomous rounds will be a future endeavor. Currently Spot is primarily controlled in teleoperated mode for radiation information gathering.[4]

Gamma Reality Inc. (GRI) provides real-time, mobile, 3D radiation mapping capabilities deployable in handheld mode, on unmanned robotic platforms (UAV/UGV)[5] and on vehicles, to enable safer, more efficient, and dynamic radiation detection missions. The core capabilities of GRI include multi-sensor data fusion and data analysis, 3D radiation mapping with situational awareness sensors, and integration of multi-sensor 3D radiation mapping systems with robotic platforms. GRI provides gamma-ray imaging and dual neutron and gamma-ray mapping capabilities based on user requests for applications including nuclear security, emergency response, safeguards, decontamination, and more.

The GRI LAMP system is a commercially available hardware package that includes the GRI 3D mapping and data fusion software to perform real-time 3D radiation mapping and data fusion. LAMP automatically fuses 3D LiDAR scans with radiation data to produce intuitive 3D radiation maps that identify, localize, and map source terms in the operating environment. LAMP can also be run in GPS mode to localize source terms on a global/satellite map. LAMP is designed to be user friendly and streams 3D maps to the user control tablet in real-time as the system moves through an environment, providing immediate, actionable information in the field. The system rapidly creates fused 3D radiation maps, which update as more data are collected, and can map large areas in tens of minutes.

The LAMP features high-resolution gamma-ray imaging using a H3D CZT[6] detector. The LAMP can provide about 10x improved source resolving power, which enables more precise source localization and differentiation if there are multiple sources in the area. LAMP provides multiple options for mapping and visualization of radiation fields. The default mapping mode on LAMP is LiDAR mapping. In this mode, LAMP automatically fuses 3D LiDAR scan data with radiation data to localize and visualize the radiation field. This mode works well in both indoor and outdoor environments and for objects ranging from small pipes to large areas with multiple tanks.[7]

[4] Videos of the Spot robot in action are available on YouTube at: *https://www.youtube.com/playlist?list=PLIL_rsmcRMZfg0JSQg4xNuPxXH5b5j1Qi*.
[5] UAV: Unmanned aerial vehicle; UGV: unmanned ground vehicle.
[6] CZT: cadmium-zinc-telluride radiation detector.
[7] For an in-depth discussion on the capability of this radiation detection system see: "Design and Demonstration of an Autonomous System for Radiological Characterization of Building Surfaces", EPRI, Palo Alto, CA: 2022. 3002023966. https://www.epri.com/research/products/000000003002023966

Demonstrating Remote Robotic Radiation Detection

The demonstration and implementation of Spot with LAMP began in late 2021 and ran through fall of 2022. Over this period the team at Surry methodically proved not only the capability of these technologies, but also tested the reliability and ease of integration of these tools into current work practices.

In the fall of 2021, Dominion held a technology demonstration day at Surry. During this event the company brought Spot on site and gave people the opportunity to see the robot up close and observe features such as operation, obstacle avoidance, range of motion, and sensor integration. The company also invited GRI to visit and give a demonstration of LAMP. The day ended with a combined technology demonstration where company personnel mounted the LAMP on Spot and mapped the Surry Admin building. The station Health Physics group quickly identified the potential impact these two technologies could have when used together.

The first pilot in the station was both a demonstration of the Spot robot's capability to operate within a nuclear facility and a proof of concept showing robotics being used to deploy radiation detection devices remotely. The company worked closely with Boston Dynamics to integrate a handheld radiation detector as a payload carried by the robot. Then personnel took the robot into the Aux building and were able to navigate three different floors of that building manually and build autonomous routes for radiation data collection. These routes were then initiated and observed by the station health physics group for a month and reviewed for radiation data consistency or any navigation issues, while also giving station personnel opportunities to interact with the robot and develop a familiarity with the technology. This experience was captured by Boston Dynamics as an industry case study.[8]

These demonstrations provided great insights on the capabilities of the robot and its navigation. These included lessons on special considerations when operating a quadruped robot such as foot placement and areas for enhancement such as improving the navigation of industrial stairs with small mid floor landings. Boston Dynamics used this feedback to further enhance the robot's capabilities with the next major system update.

The second pilot was to monitor a spent fuel cask move from the fuel building to the Independent Spent Fuel Storage Installation (ISFSI) at Surry. This initiative had two main goals. The first was to utilize the GRI LAMP technology to evaluate neutron radiation levels and shielding effectiveness in a variety of applications. These included the NUHOMS EOS cask in the cask closing area, during cask loading onto the transport vehicle, transfer to ISFSI, loading into the horizontal storage module, and general area dose rates around the ISFSI protected area fencing. The second was to evaluate use of Spot, carrying the GRI LAMP, during cask movements for ALARA purposes, and test Spot's long range antenna system. To do this Dominion used the combined technologies in parallel with current monitoring procedures and validated the data collected by LAMP and Spot against that gathered through traditional methods. Again, the company found the limits of the new technology as it tested LAMP in this evolution. As noted in the previous example, Dominion provided feedback to the vendor, which enabled the vendor to improve data processing in the next deployment. Overall, LAMP created reasonable 3D images of the neutron dose field and provided reasonable dose rate images. The Spot robot performed well as a carrier of the LAMP. It proved to be a good ALARA tool for using the LAMP as it was able to be operated from a distance and move around the work area with minimal distractions to the crew. The Spot operator was able to remain outside the ISFSI fence, in a vehicle, and operate Spot around the ISFSI work area successfully.

In a third demonstration, Dominion used the two technologies in an outage support role for the plant's fall 2022 outage. The company used LAMP mounted on SPOT to evaluate the effectiveness of shielding in the in-core sump room on the radiation levels on the RHR flats. The GRI LAMP performed well in performing this task. The radiation level gradients were well represented and consistent with the levels found during previous RP surveys with handheld instrumentation. Figure 3 depicts the image from the software and clearly indicates where the radiation levels are elevated along the rear of the in-core sump room doghouse, as expected due to lack of

[8] Available at https://www.bostondynamics.com/resources/case-study/dominion-energy-0.

shielding, and relatively low levels along the front of the doghouse. A less pronounced elevated radiation level can be seen around the RHR pumps and piping.

The Spot robot performed quite well in containment. It managed navigation through all the usual containment obstacles without issue. The robot did not contact any plant equipment, navigated the annulus areas and RHR flats without fail, and utilized the personnel hatch stairs and ramps without issue. It was necessary to manually lower the robot onto the RHR flats, as it cannot yet scale ladders. This activity, while cumbersome, was effective in getting the robot to the area to scan. Overall, the initiative proved successful. The GRI LAMP provided good visualization of the radiation levels and the SPOT robot provided an excellent method of moving the LAMP around the space. The entire mission, including almost an hour of actual scanning of RHR flats resulted in 5 millirem personnel exposure.

The success of this initial project led to the combination of Spot and LAMP being used to access the shielding around the fuel transfer canal during fuel movement. Additionally, personnel mapped radiation throughout containment including in the Loop room and in the RCP motor cubes. Finally, personnel followed up on the previous fuel move pilot and completed a full mapping of all four ISFSI pads. These were all performed with the robot operators having minimal personnel exposure while providing the most complete radiation visualization ever produced for all these applications.

The success of this innovation has been noted inside the company and throughout the industry. Over the course of this project, it has been presented at several meetings, including: 2021 NEI Industry Innovation Workshop, 2022 NEIL Conference as a featured topic for Nuclear Innovation, 2022 Women In Nuclear National Conference, and 2022 Dominion Energy Innovation Expo. Dominion's efforts also garnered favorable mention in the local press, with an article in the Virginia Mercury newspaper.[9] The innovation team also promoted this innovation through site visit to stations across Dominion's nuclear fleet and corporate offices, visits and demonstrations at local universities and community events, the Dominion Energy Envision Tomorrow Feb 2023 Charter of the Month, 2023 EPRI Radiation Management and Source Term (RM&ST) Workshop. Additionally, the project champions have served on Boston Dynamics Customer Advisory Council, EPRI's Nuclear Robotics Technical Advisory Group, and as contributors to the EPRI Mobile Ground Robotics User Guide (currently in development) to ensure the learning from these efforts are shared throughout the industry. To further publicize the success of the Spot/LAMP project, one of the project champions has posted a comprehensive list of project activities on his LinkedIn page.[10]

Pictures of Spot in the plant are provided in Figures 1-5.

Safety

With the right sensor payload, robots like Spot can be used to assess conditions in potentially hazardous spaces without exposing personnel to those hazards to gather initial data.

Cost Savings

The combination of Spot and LAMP is a disruptive technology that is expected to result in process improvements and efficiency gains as the application of this tool becomes more prevalent in the radiation monitoring department.

Productivity/Efficiency

Data entry and survey map development becomes automated for initial surveys of areas and teams can be

[9] "The 21st century's canary in the coal mine is a robotic dog named Spot", https://www.virginiamercury.com/2022/09/01/the-21st-centurys-canary-in-the-coal-mine-is-a-robotic-dog-named-spot/
[10] https://www.linkedin.com/in/josh-bell/recent-activity/shares/

more effectively deployed to access specific areas following an initial area survey.

Transferability

Both these technologies are commercially available and are easily deployable at any nuclear facility.

Team Members

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Additional Information
Figure 1 – Spot in Containment

Figure 2 – Spot During Fuel Move

Figure 3 – Capture RHR Flats

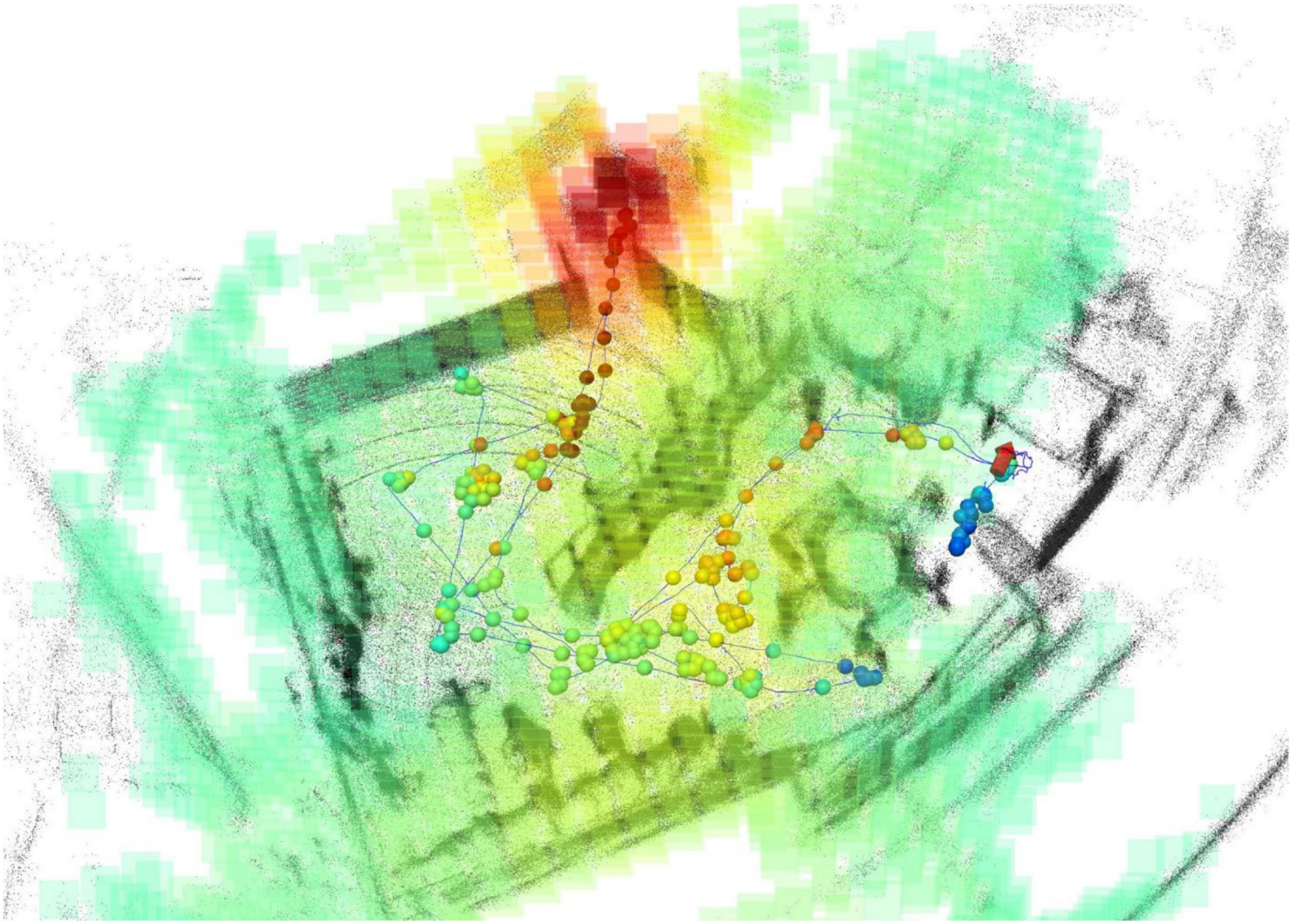

Figure 4 – Containment Scan Small

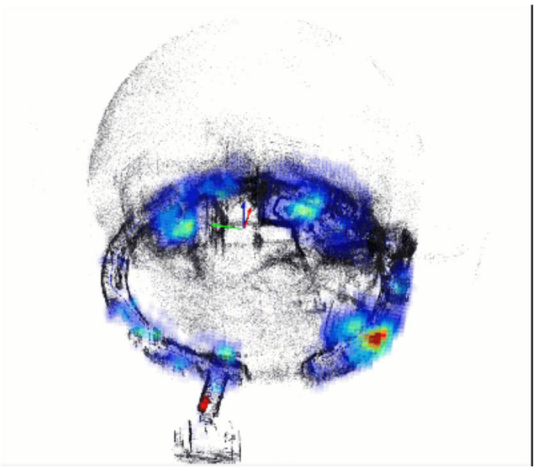

Figure 5 – ISFSI Pad