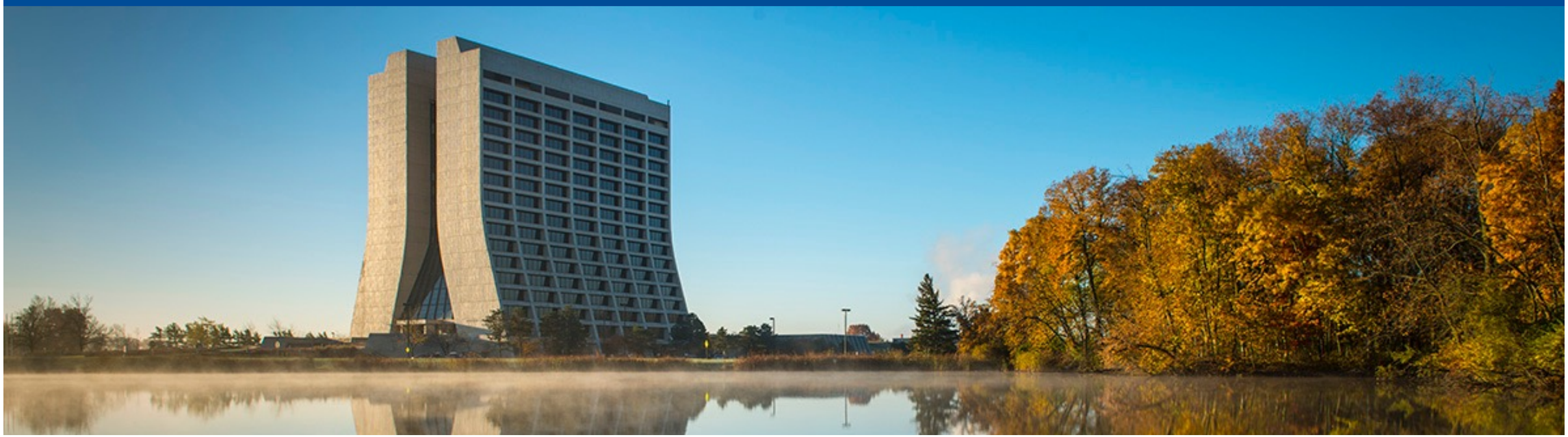


AD Robotics Initiative: The SPOT Project

Noah Curfman, Adam Watts, Mayling Wong-Squires – Accelerator Division (AD)

Fermilab 2022 All Engineers Retreat

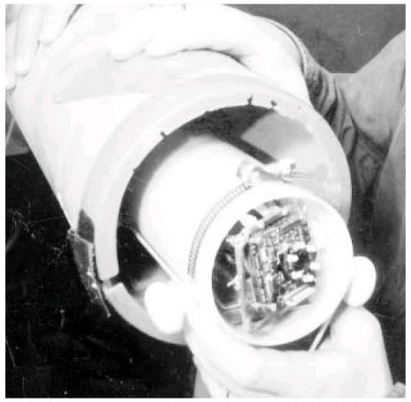
23 February 2022

Outline

- Overview of AD Robotics Initiative
- Introduction to SPOT
- Radiation Survey Project
- Application Ideas for SPOT
- Summary

History of Robots in the Accelerator Division

1991: Remote-controlled hardware working inside a Switchyard beam transport pipe: located vacuum leak, clean the surface area, install an epoxy patch (Ref: Numi docdb 546)



A robot camera developed by Todd Johnson and Duane Plant is inserted into the LCW system.

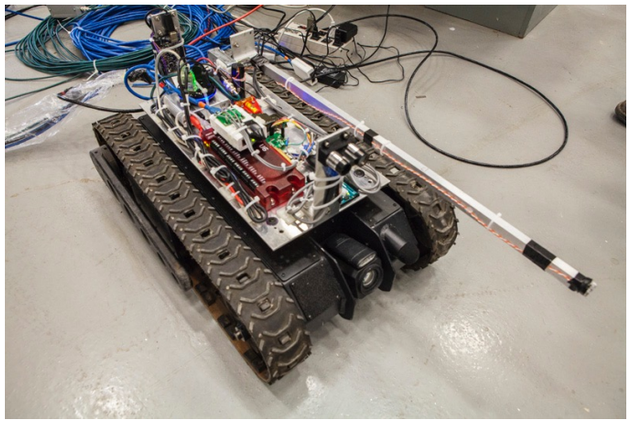
1998 - Camera to visually inspect the Low Conductivity Water pipes in the Main Injector (Ref: Ferminews)

Booster's MARVelous Robots

From Fermilab Today March 23, 2005

MARV I and MARV II with their builders, (from left to right) Ray Tomlin, Greg Brown, John Larson and Bob Florian.(Click on image for larger

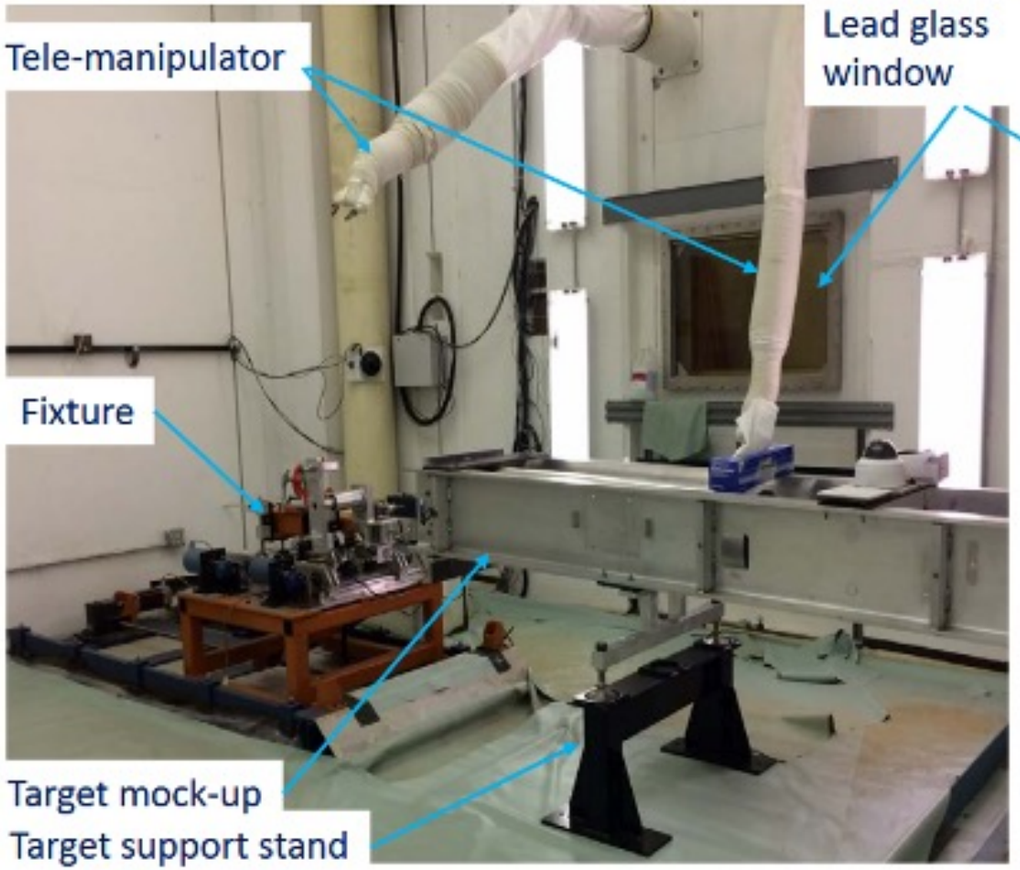
2005 – Mobile Arm Radiation-measuring Vehicle (MARV), used for visual inspection and radiation surveys during Booster operation (Ref: Fermilab Today)



2015 – Robot named Finding Radiation Evidence in the Decay pipe (FRED), remotely controlled to survey the region between the target horn and the decay pipe in the Booster Neutrino Beam (Ref: Fermilab-pub-18-334-ND)

Telemanipulators at the Target Autopsy Facility (Work Cell)

Inside the Work Cell (1 rem/hr)



Outside the Work Cell

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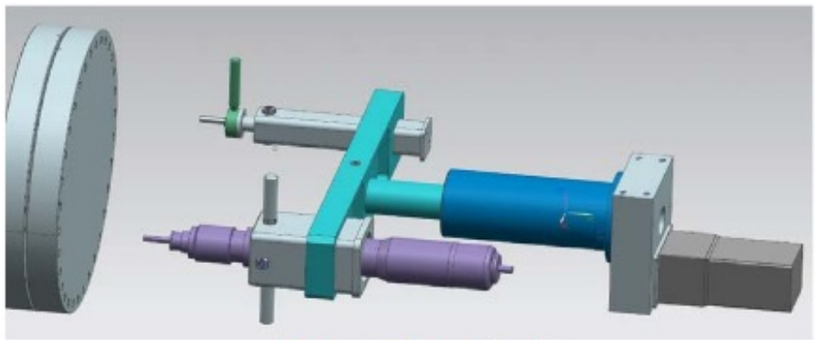
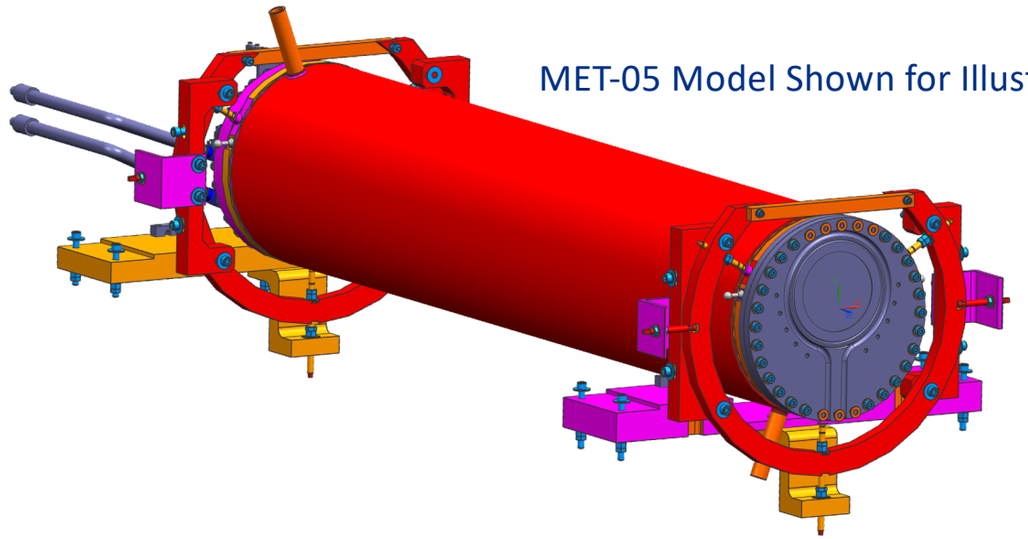
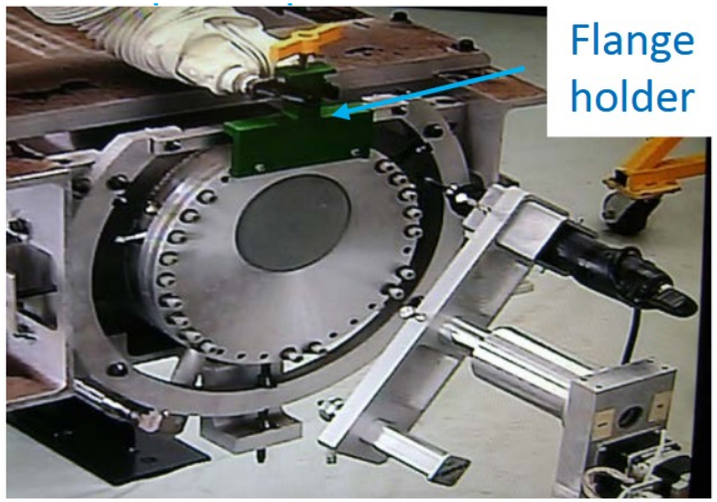
Current telemanipulators help to remove the outer flange



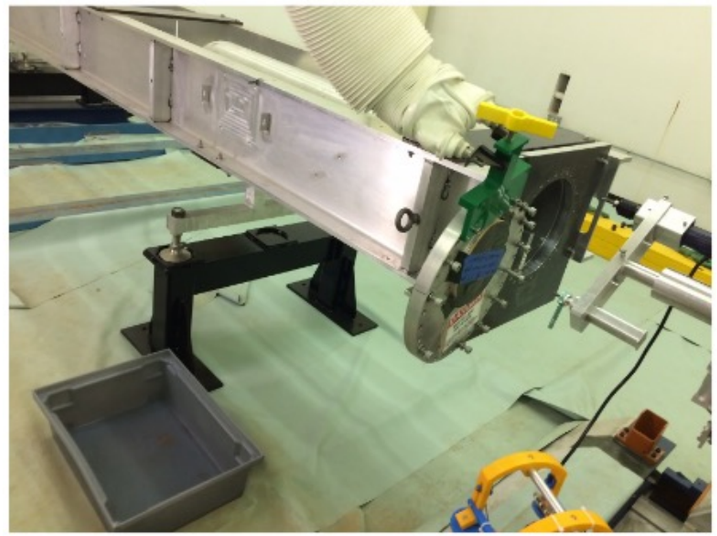
Screw driver tool



MET-05 Model Shown for Illustrative Purpose



Flange holder



Motivation of Using Robots

Then and now…Increase worker safety and Increase efficiency of accelerator and target operations

Robot Tasks

- Survey and log radiation data
- Obtain photos / stream videos
- Access hard-to-reach places
- Telemanipulation of parts
- Automate repetitive tasks

Benefits

- Reduce exposure to environmental hazards like radiation
- Reduce beam-off time due to preparing for personnel to enter the tunnel or target area
- Free up personnel efforts to focus on complex tasks

Formation of the AD Robotics Initiative

Why:

- Demonstrate how robots can support current and future beamlines
- Enhance personnel safety
- Increase beam operational time
- Start with exploratory projects to investigate techniques and technologies

Who: Anyone who is interested!

- Multi-disciplinary team: AD engineers, engineering physicists, software developers technicians
- Collaborators: Experts around the lab, in universities, other national labs

When: 2019

Mission Statement

"The AD Robotics Initiative's mission is to create and use robotic devices to enhance personnel safety and increase efficiency of accelerator operations, maintenance, and upgrade installations. By creating collaborations between robots and humans, the initiative will demonstrate how robotics will shape the future of technical support for the Main Injector, Booster, PIP-II, target handling areas, and LBNF. To understand how robotics best fits this purpose, the initiative is planning and undertaking several exploratory projects to try various techniques and technologies."

Goals of the AD Robotics Initiative

1) Use robotic devices as remotely-controlled and automated diagnostic systems for the accelerator and its subsystems during operations and maintenance
2) Use robotic devices to repair the accelerator, its sub-systems, and its associated infrastructure
3) Use robotic devices to sort, move, and stage equipment and parts before, during, and after fabrication and maintenance of the accelerator, its sub-systems, and its associated infrastructure
4) Use robotic devices as tools to remotely plan and train personnel on critical jobs

Initial Focus – Establishing the Foundation

Start with “remotely-controlled diagnostic systems”

Develop expertise

- Explore open-source tools and low-cost hardware as well as off-the-shelf industrial solutions
- Develop expertise to build, operate, and maintain devices that do not solely depend on proprietary systems
- Balance of in-house expertise with commercial solutions remains a priority in the strategic plan of the Robotics Initiative

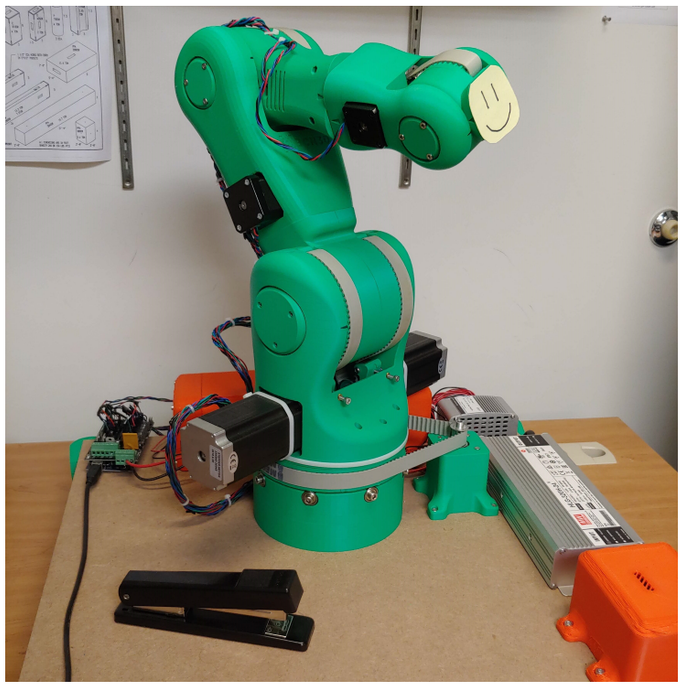
Establish working relationship with ESH

- Develop practices now that can be part of future FESHM-like chapter
- Develop TRAIN course to certify future robot operators
- On-going with each new device

In-House Efforts

Common features: Arduino / Raspberry Pi,
Open-source designs and code, 3D printed parts

Remote Viewing Robot (RVR), successor to MARV II, in the Main Injector Tunnel



Robotic arm based on the open-source BCN3D Moveo design, controlled by Arduino and ROS

NuMI magnetic horn longitudinal field-mapping system

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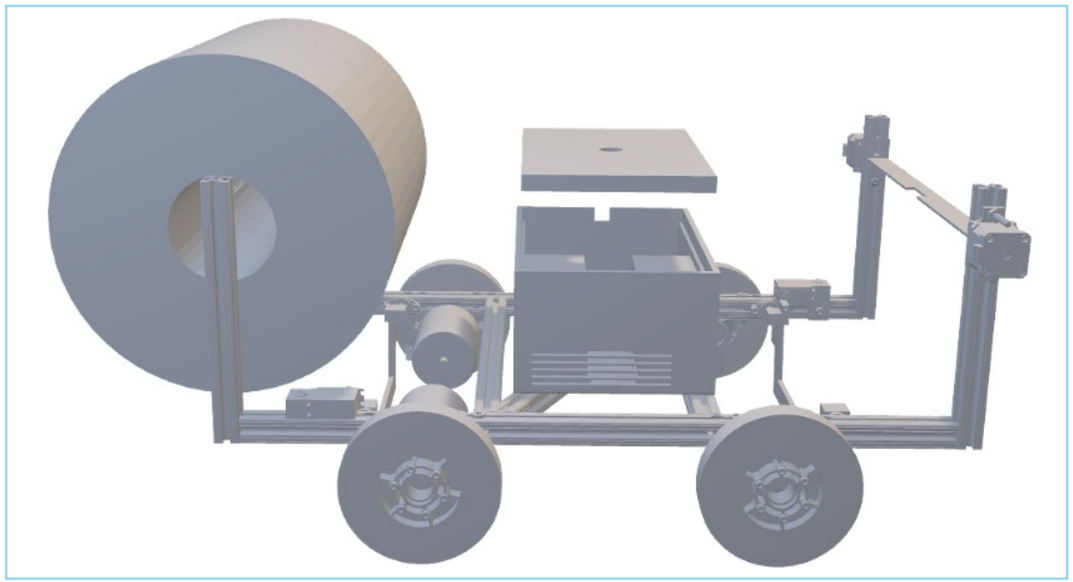
Student Projects

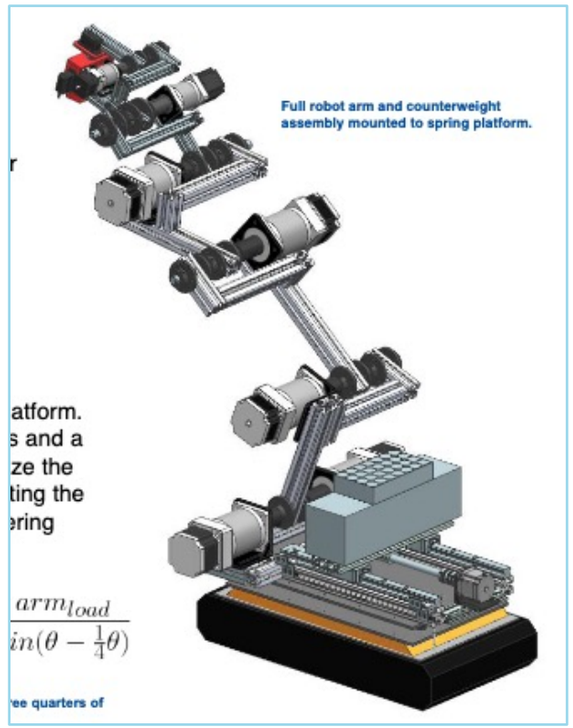
3D Radiation Mapping Quadcopter
(University of Illinois – Chicago, Engineering Expo 2020 and 2021)
Mentor: Katsuya Yonehara

Student Projects (cont'd)



Robotic Radioactive Dust Collector (University of Illinois – Chicago, Engineering Expo 2020)

Mentors: Noah Curfman, Rob Ridgway



Counterweight for Long Reach Robotic Arm (Community College Internship, 2020, 2021)

Mentors: Kris A. Anderson, Adam Watts

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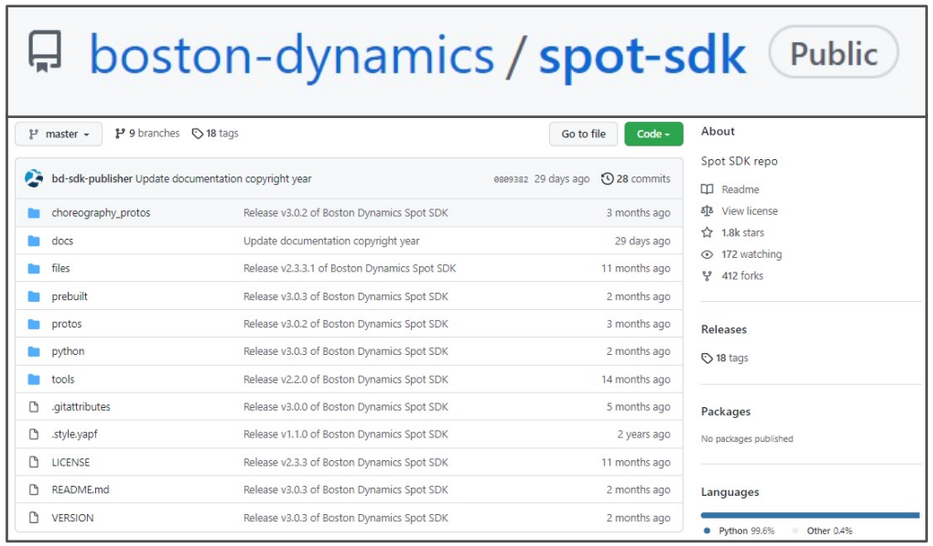
Remotely Communicate with a Commercial Robot in the Tunnel

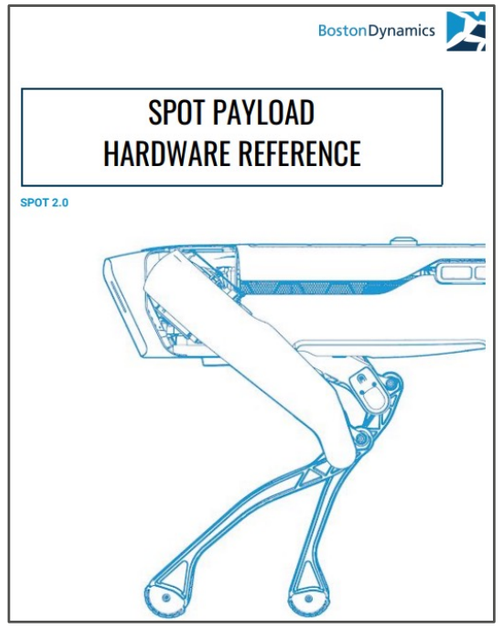
Establish a foundation of tools and technical requirements to remotely communicate with SPOT and future robots in the tunnel

- Existing and new WiFi capabilities
- ACORN's 5G R&D program
  - Study 5G feasibility in tunnel
  - Potential communication mechanism for future robotic telemanipulation (example: 2-way communication for repairs of systems inside the tunnel, live-streaming data, video/audio upload)
- Contribution towards developing functional requirements for the modern accelerator control system (participating in Accelerator Operations Requirements Workshops)

Why Spot?



github.com/boston-dynamics/spot-sdk



support.bostondynamics.com

Tradeoffs and Limitations

High Initial Cost

- Payloads, Batteries, Port caps
- Significantly reduced development time

Closed Source Base Functions

- Hardware replacement challenges
- No ROS knowledge needed

https://husarion.com/

https://clearpathrobotics.com/

https://stanleyinnovation.com/

https://waypointrobotics.com/

ROS

ROS

ROS

ROS

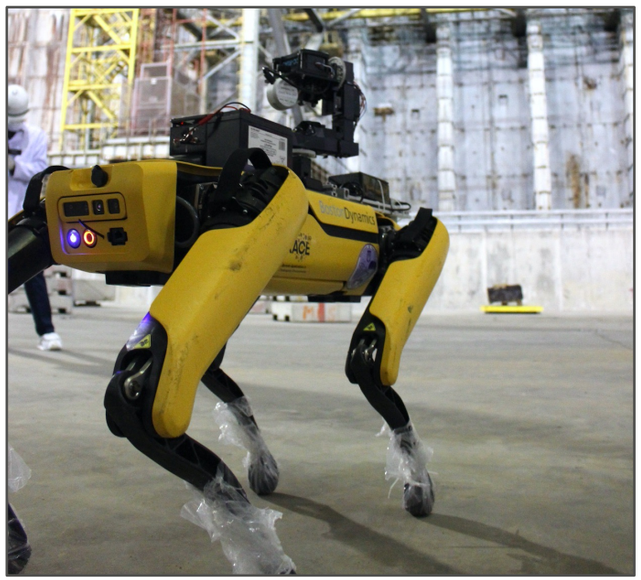
ROS 2

ROS 2

Tradeoffs and Limitations

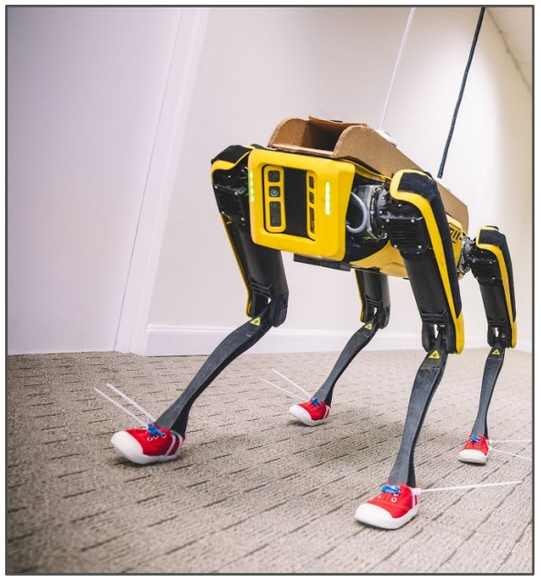
Vulnerable to Radiation

- Not an inspection robot for high rad areas
- PPE in use and in development
- Boston Dynamics excited about accelerator applications



https://spectrum.ieee.org/boston-dynamics-spot-chernobyl

https://tinyurl.com/Spot-in-Nuclear-Environments



https://www.youtube.com/watch?v=-R8wUybrspo

Application: Radiation Surveys

Develop custom payload and data acquisition to eventually automate pre-access, beam-off radiation surveys.

- Reduce ES&H Radiation Control Technician dose
- Free up ES&H personnel for higher-value tasks
- Digitize survey results at high resolution, include photographic images
- Estimate systematic errors to produce confidence intervals in results

Challenges

- Precise location awareness of Spot in enclosure
- Synchronize, analyze, and store data acquisition from multiple sources
- Work toward meeting stringent standards of ES&H so survey results can be “official”: sensor and digitizer calibration, data integrity
- Autonomous navigation in enclosures

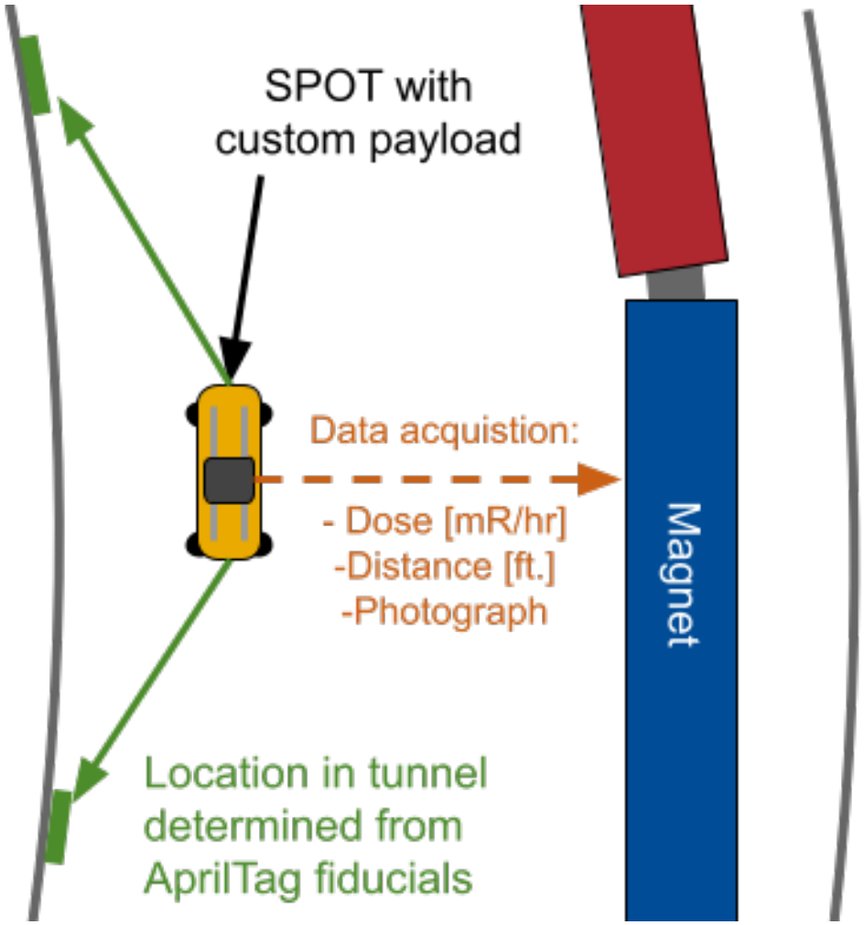
Radiation Survey Proposed Methodology

Spot custom payload to carry

- ES&H-provided radiation survey meter
- Stereoscopic camera
- Digitization electronics

Position in tunnel determined by Spot localization using AprilTag fiducials.

Stereoscopic camera to provide photograph and distance information for each radiation dose data point.



Radiation Survey: Measuring systematic errors

Localization

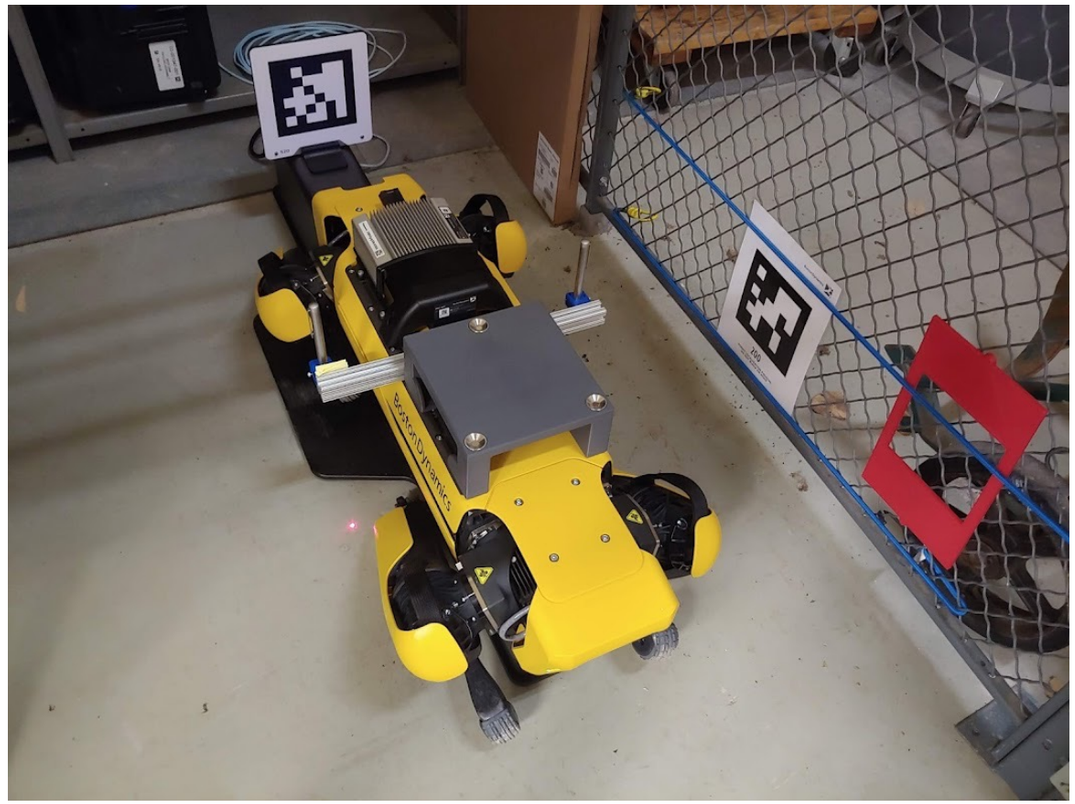
- Developed 3D-printed payload to hold alignment fiducials.
- Planning to test localization precision by cross-referencing with Metrology

Distance to accelerator component

- Testing stereoscopic camera and laser pointer: camera sees laser dot, software finds distance information corresponding to those pixels.

Radiation survey meter

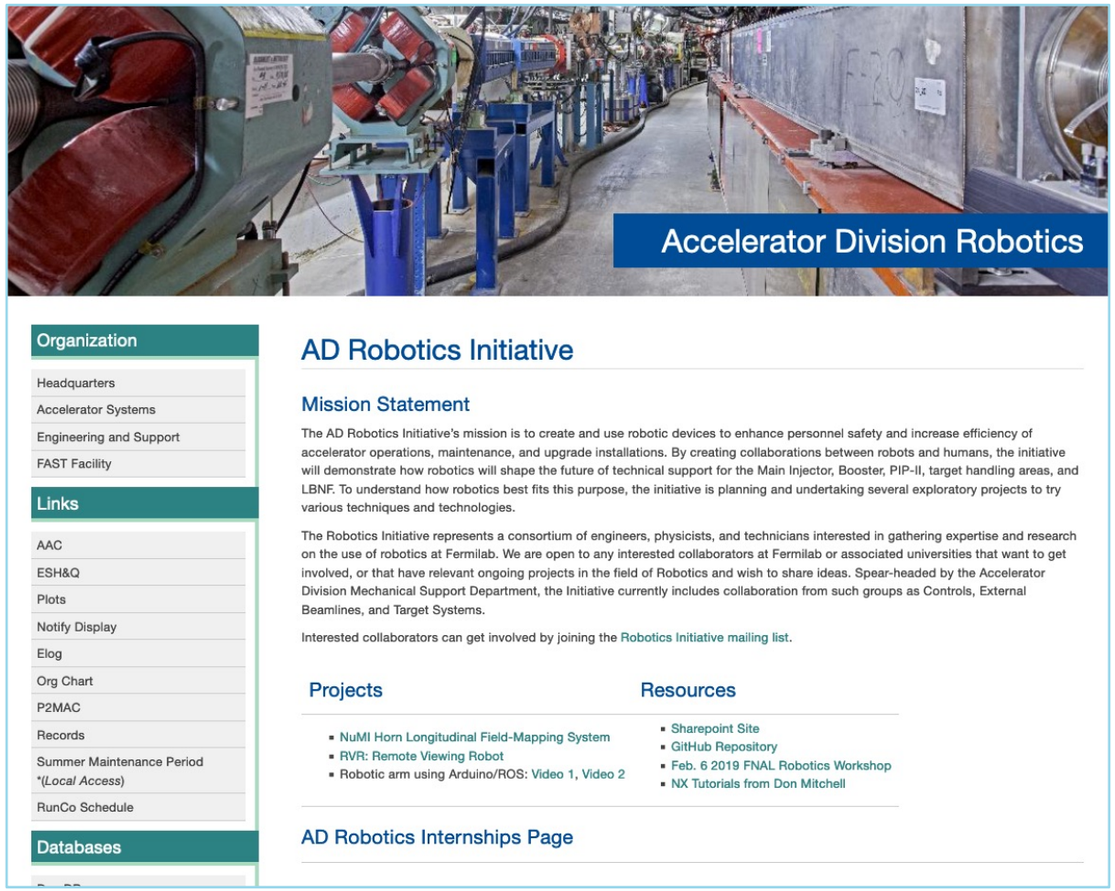
- Working with ES&H on requirements for a regularly-calibrated meter with analog voltage output
- ES&H calibration measures meter systematics



Spot on charging dock with localization test payload and nearby AprilTag fiducials

Summary – the SPOT Project

- Exciting part of AD Robotics Initiative
- SPOT capabilities match many needs for traversing the tunnels
- Immediate application: Radiation Surveys
- Use to establish technical requirements to remotely control tunnel robots
  - Contribute to defining functional requirements for a modern accelerator control system



https://ad.fnal.gov/robotics/

Applications Ideas for SPOT and robot teleoperations

- Automated tours of accelerators
- Data collection to train AI neural networks to detect anomalies (unusual radiation patterns, sound of LCW pumps indicating bad bearings, water leak visual detection)
- Beyond the accelerator: Reconnaissance of confined spaces, radiation berms, assisting Fire Department response
- Remote manipulation: either developing manipulators that can use human tools, or engineering systems with robotic manipulators in mind for maintenance/repairs. Examples: vacuum leak checking, water leak repairs

What other ideas do you have?