Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Fermilab Accelerator Division Robotics Initiative

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Workshop on Robotics Use in Accelerators, Targets, and Detectors

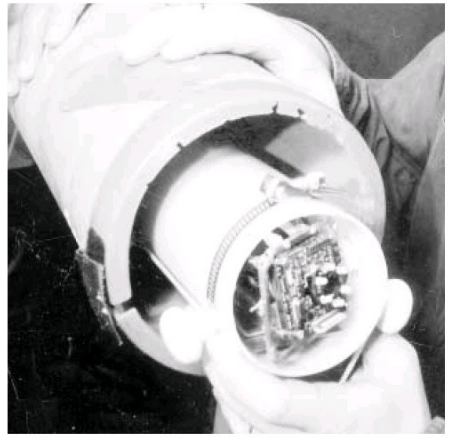
23 March 2022

Outline

- Overview of Robotics in the Accelerator Division
- Goals and Objectives of AD Robotics Initiatives
- Current Efforts
- Future Efforts
- 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.

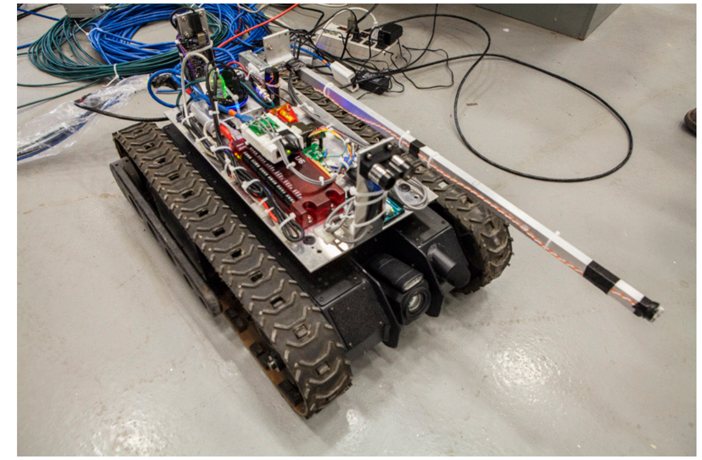
1998 - Camera to visually inspect the Low Conductivity Water pipes in the Main Injector (Ref: Ferminews)

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)

Motivation of Using Robots for Accelerator Operations

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 personnel exposure to environmental hazards like residual 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

Who:

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

When: 2019

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

Strategic Plan for Robotics

Vision: Establish a Robotics Support Center in alignment with accelerator machine experts to develop and deploy this technology efficiently.

- Provide in-house, interdisciplinary technical expertise
- Standardize and vet reliable solutions
- Create safety guidelines for robotic devices to interact with personnel and accelerator

Goals of the Robotics Strategic Plan

1) Use robotic devices as automated and remotely controlled 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

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

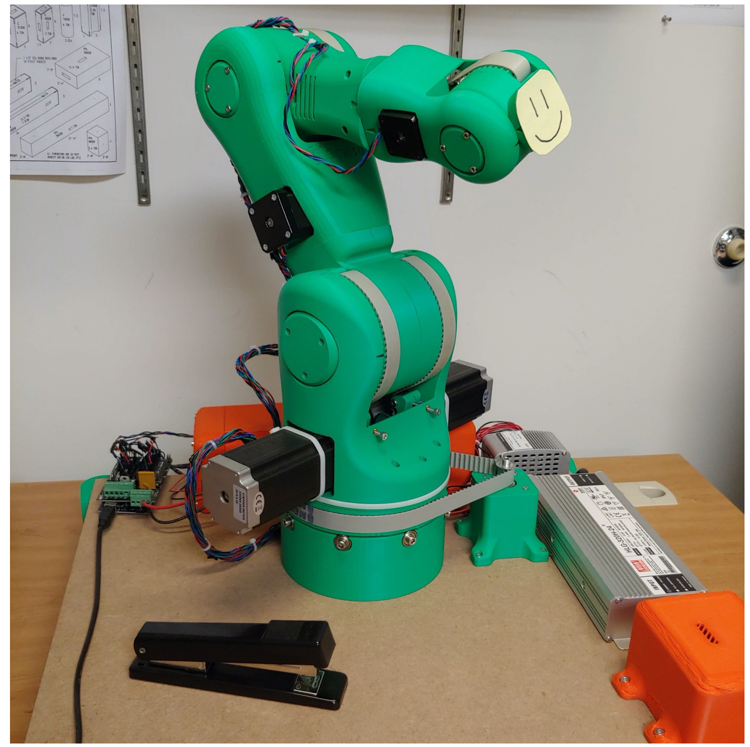
Establish working relationship with ESH (Environment Safety and Health) Section

- Develop practices now that can be part of future chapter in the lab's safety manual
- Develop training 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

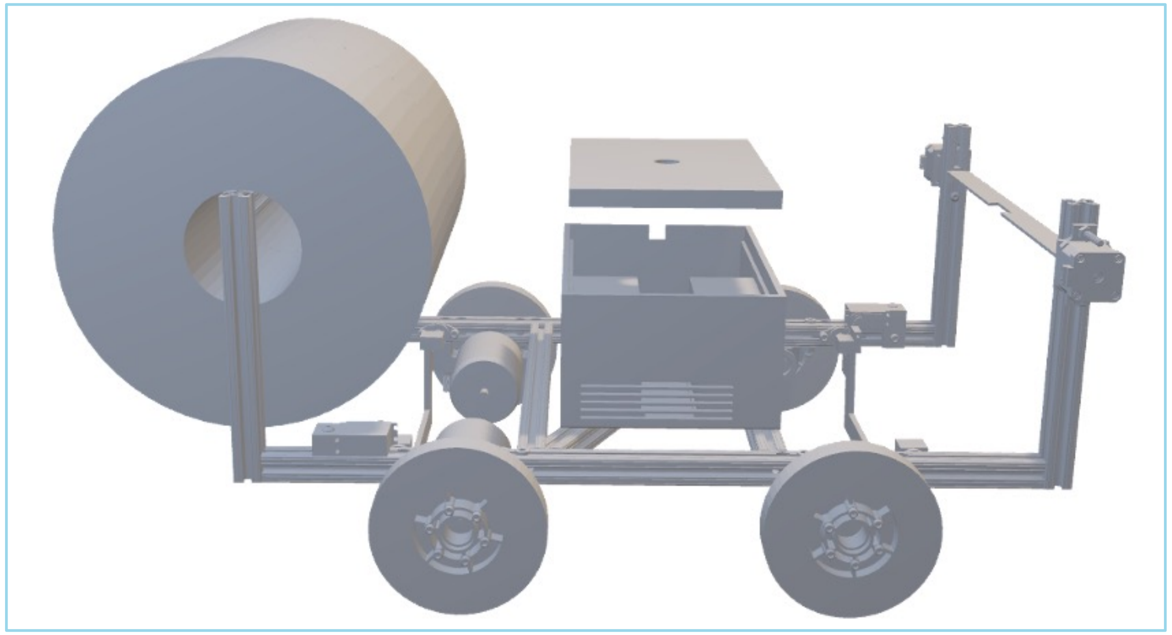
Remote Viewing Robot (RVR), successor to MARV II, in the Main Injector Tunnel



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

NuMI magnetic horn longitudinal field-mapping system

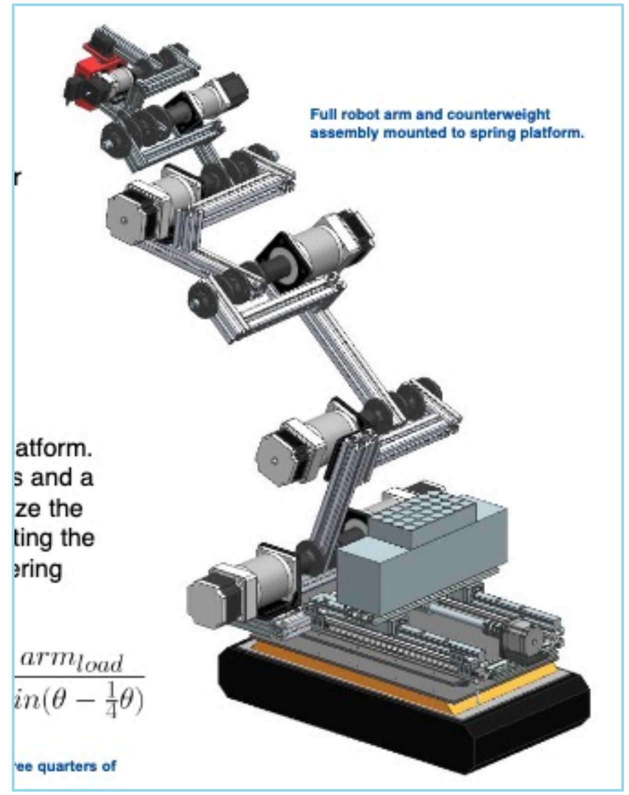
Student Projects



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

Objectives

1. Communicate with robot in accelerator tunnels and enclosures
2. Automated robot with diagnostic systems
3. Remotely controlling a robot for diagnostic purposes

Objective 1: Communicate with a Robot in the Tunnel

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

- Use existing accelerator control system for telemetry data (communicate and log robot state)
  - Automated robot
  - Location of robot
  - Robot operational status
- Existing and new WiFi capabilities
- 5G R&D program of Accelerator Control Operations Research Network (ACORN) Project
  - Evaluate 5G feasibility in accelerator tunnels
  - Potential communication mechanism for future robotic telemanipulation (example: 2-way communication for repairs of systems inside the tunnel, live-streaming data, video/audio upload)
- Developing functional requirements for the accelerator control system
  - Specify requirements for latency, flexible data structures, logging capabilities, video streaming, human interfaces

Communicating with SPOT robot

- Capabilities match many needs for traversing the tunnels
  - Multiple cameras
  - Object avoidance
  - Flexibility
  - Mobile in variety of terrains (surfaces, steps)
  - Communicates using WiFi
    - Has capabilities to communicate over 5G

SPOT robot at Fermilab

Objective 2: Automated Robot for Radiation Surveys

Develop custom payload and data acquisition

- Goal: automate pre-access, beam-off radiation surveys
- Numerous benefits
  - 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

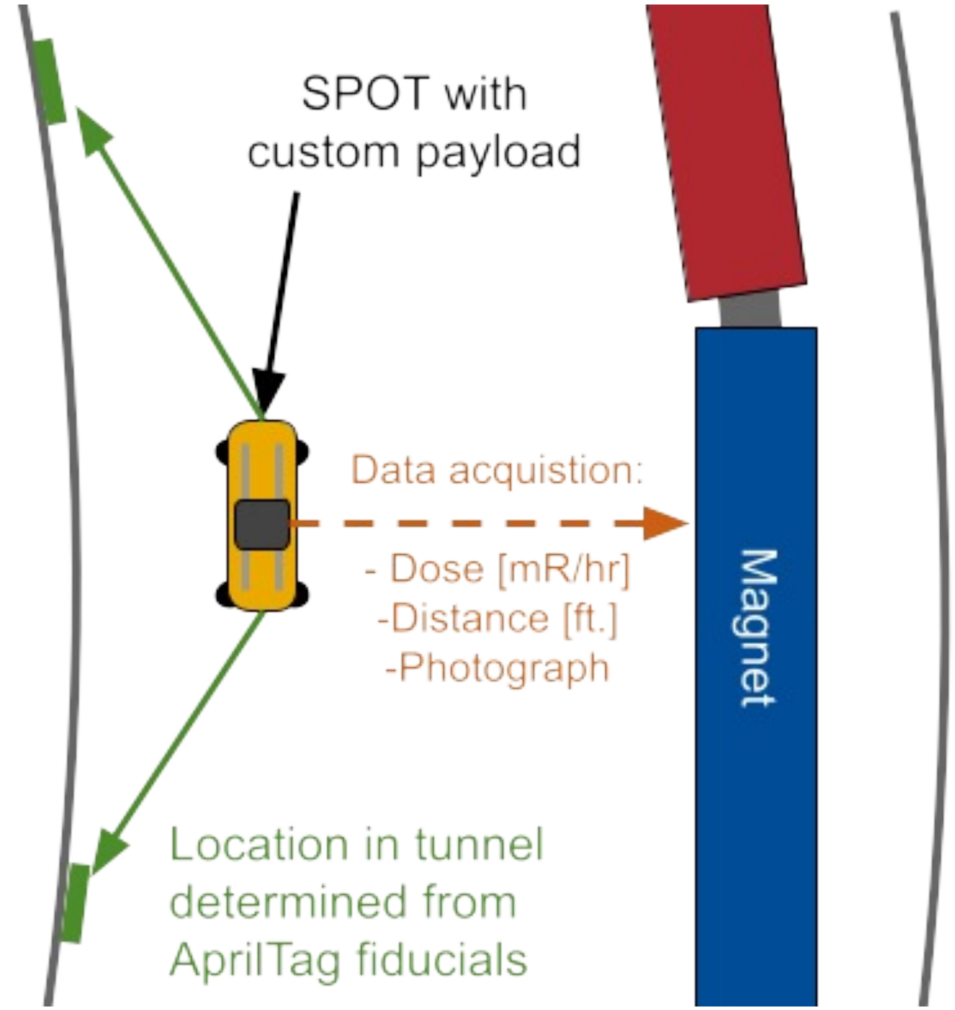
- Precise location awareness of Spot in enclosure
- Synchronize, analyze, and store data acquisition from multiple sources
- Work toward meeting stringent standards of ES&H so survey results can be “official”: sensor and digitizer calibration, data integrity
- Autonomous navigation in enclosures

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

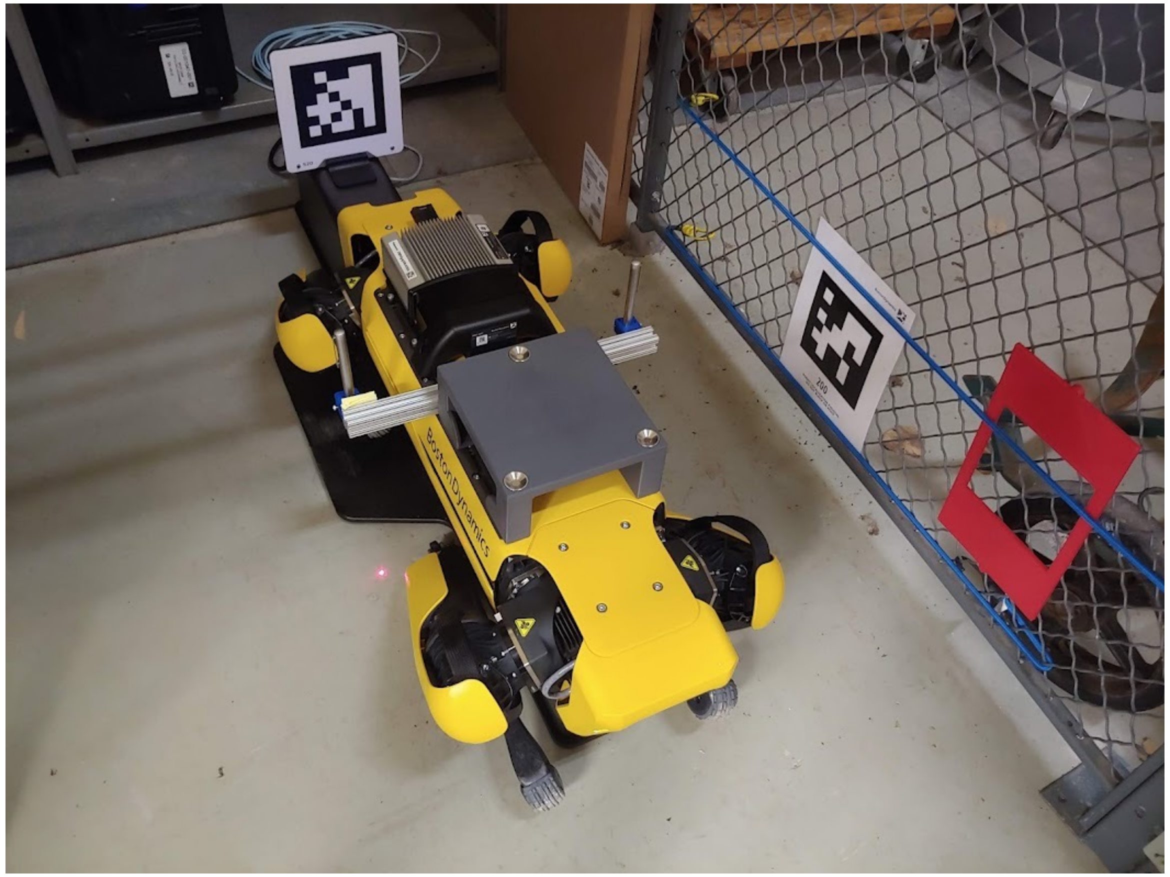
- Developed 3D-printed payload to hold alignment fiducials.
- Planning to test localization precision by cross-referencing with Metrology

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

Future Efforts of the Robotics Initiative

- Not a herd of SPOT robots
  - Dependent on vendor for repairs, system upgrades, and replacements
  - Costly
  - Not aligned with Robotics Strategic Plan
- Robotics Strategic Plan
  - In-house expertise to repair and upgrade the robots that are in use (Robotic Support Center)
  - Use of open-source coding and commercial hardware

Objective 3: Remotely Controlling a Robot for Diagnostic Purposes

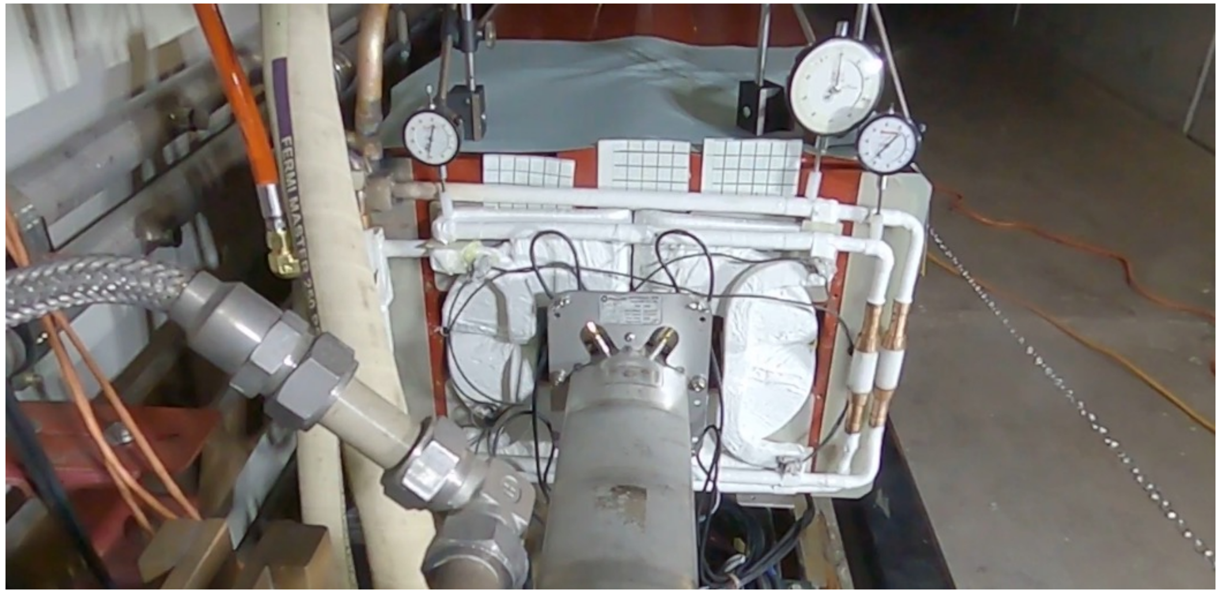
Remotely-controlled robot with multiple data gathering capabilities

- Live-stream video
- 3D mapping of accelerator and tunnel (camera and LIDAR)
  - Record of the physical space
    - Identify physical changes over time
    - Use data for measurements and job planning
- Robotic arm to extend reach to spaces beyond the tunnel aisle
- Record other data: audio, radiation, temperature, humidity
- Use neural networking / AI to "train" robot to detect anomalies
- Look to experts – learning and collaboration
  - Remotely navigate robot more intuitively
  - Process the data that is logged
  - Optimize the data and information that is sent through the accelerator control system

Immediate Use

Example of use: diagnosing root cause of water leak in magnet in high radiation area

- Live stream or record video of unexpected movement when magnet is energized, leading to fatigue stress cracks in water manifold
    - Personnel are not allowed in the tunnel when magnet is energized
- Ability to move camera for inspections close-up and from more than one perspective
- Ability to drive camera to other magnets for comparison
- Reduce exposure of personnel to multiple hazards (radiation, electrical, magnetic field)
- ESH pre-approval for robotics use in well-defined roles



Main Injector Q309 Magnet
Water Manifold Monitored for Movement

Summing Up

- Motivation for using robots in accelerator operations
  - Increase personnel safety
  - Increase beam operation efficiency
- In beginning stages of Robotics Strategic Plan
  - ACORN 5G R&D funding → Learning to remotely communicate with SPOT robot
  - Automate radiation surveys using SPOT robot
  - Remotely control a robot for diagnostic purposes
- Vision of Robot Support Center
- Seeking collaboration with experts to help us to advance goals more quickly