# Deployment and Operation of the Remotely Operated Accelerator Monitor (ROAM) Robot

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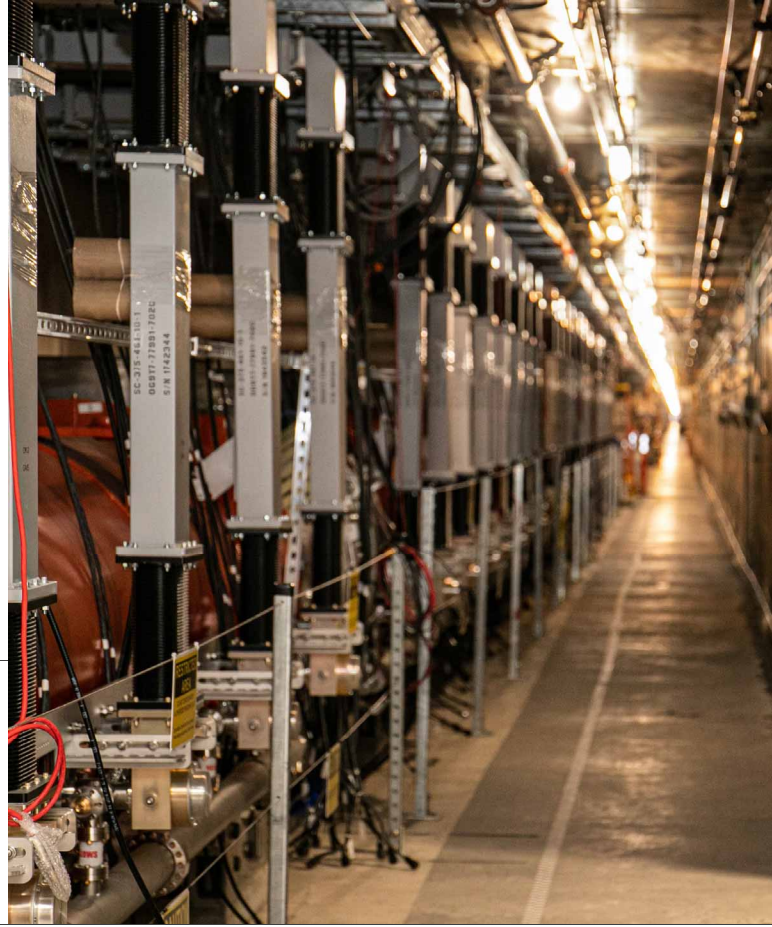


SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

# Introduction and Motivation

- SLAC National Accelerator Laboratory is a US DOE lab operating multiple particle accelerators and scientific experiments
- Accelerators are highly complex machines that need to be continuously monitored for performance and safety
  - Currently relies on a network of sensors in fixed locations
  - Non-routine testing or troubleshooting interrupts operations due to the radiation environment
- Need for ad-hoc quick deploying monitoring system
  - ROAM: a Remotely Operated Accelerator Monitor
  - Commercial Off-The-Shelf (COTS) components, open-source software

# Related Work

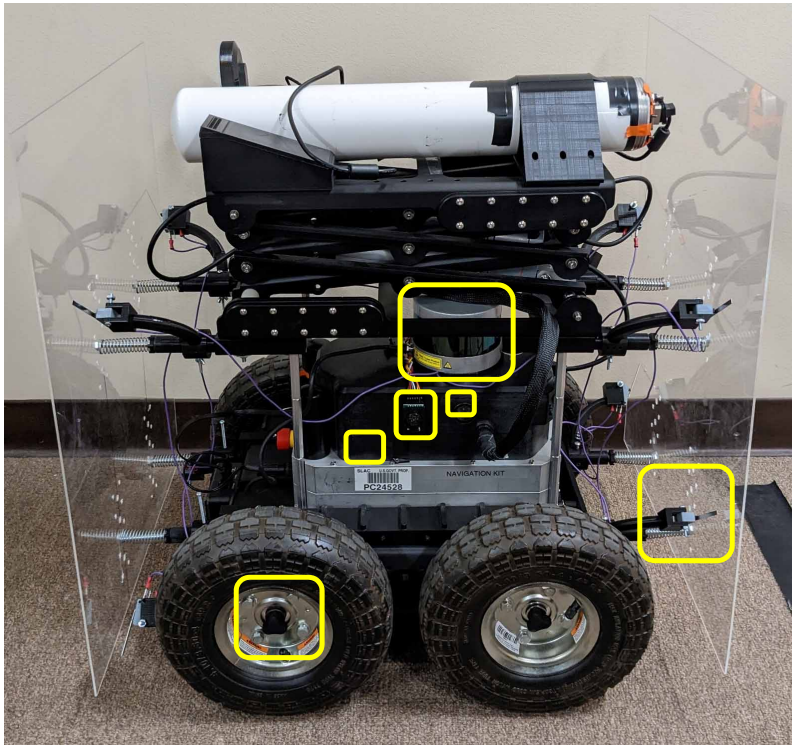
- Accelerator labs are increasingly adopting robotics for many applications, including monitoring and manipulation
  - Radiation mapping at Variable Energy Cyclotron Center (VECC)
  - MARWIN robot at European X-ray Free-Electron Laser (XFEL) with 3-axis arm
  - i-TIM monorail robot above Large Hadron Collider (LHC) at CERN
  - Cernbot at CERN carries two manipulator arms for complex interventions
  - Omnidirectional wheeled robot with arm-mounted radiation sensor at CERN
  - CERNTAURO framework for real-time robot control
  - Vacuum chamber internal inspection robot at FAIR's heavy ion synchrotron SIS100
- Most accelerator robots are purpose built, few use COTS components and open-source software
  - "PhotonBot" for environmental monitoring inside Taiwan Photon Source (TPS)
- While several labs have deployed robots, there is no de-facto standard and all were designed internally
  - Use of COTS components and ROS open-source software aims at facilitating collaboration with other accelerator laboratories

# ROAM Overview

- ROAM: A Remotely Operated Accelerator Monitor
  - Mobile robot sensor platform
  - Augment operator capabilities
  - Non-routine testing and troubleshooting
  - Uses COTS components and open-source software
  - Not Radiation hardened
- Areas of interest
  - Accelerator housings
  - Support buildings
- Safety Requirements
  - Non-autonomous
  - Automatic collision avoidance
  - Backup safety systems
  - Must absolutely avoid any collisions because of highly sensitive and costly equipment

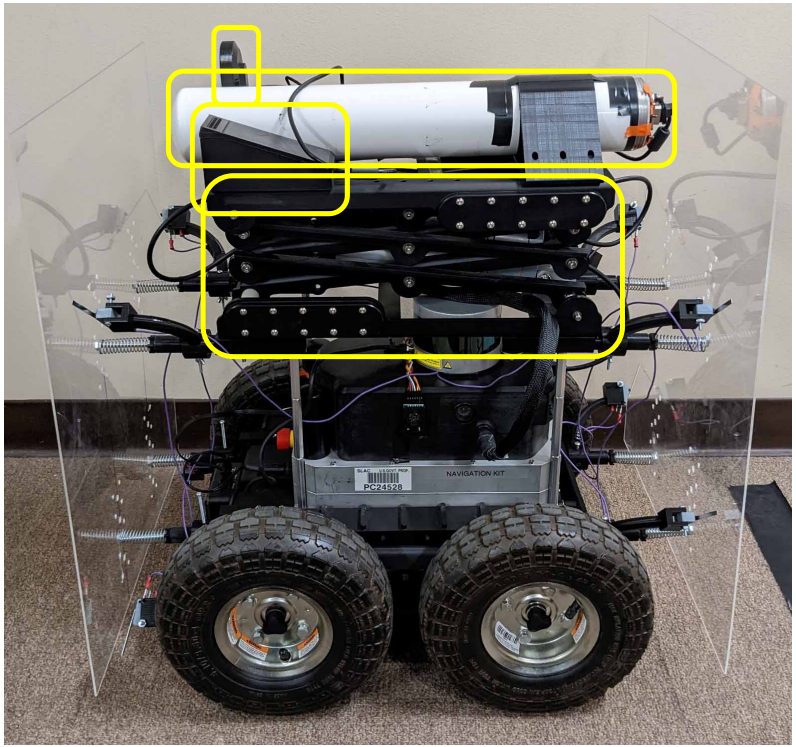
# Robot Hardware

- Rover Robotics 4WD Rover Pro
  - 100kg payload capacity
  - 294Wh Li-ion battery
  - Charging dock
- Navigation payload
  - Nvidia Jetson TX2, Arduino Mega 2560
  - Wheel odometry
  - Inertial Measurement Unit
  - 4 RGB cameras with headlights
  - Ultrasonic sensors
  - 3D LiDAR
  - Acrylic glass bumpers with limit switches



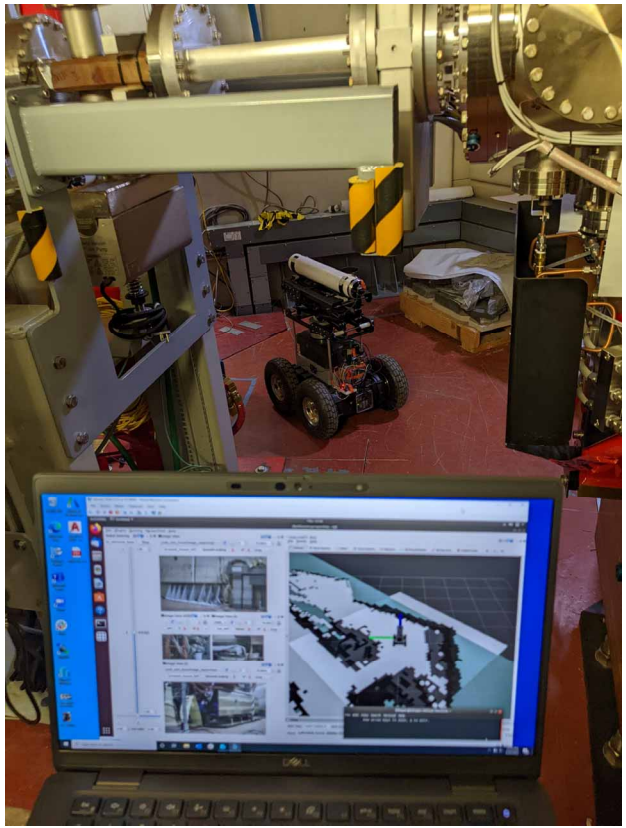
# Configurable sensor platform

- Extendable scissor lift
  - Adds 66cm (26in) height
  - USB hub
- Sensors
  - Canberra EcoGamma-G environmental radiation monitor
  - Seek Thermal camera
  - RGB webcam with microphone and spotlight*



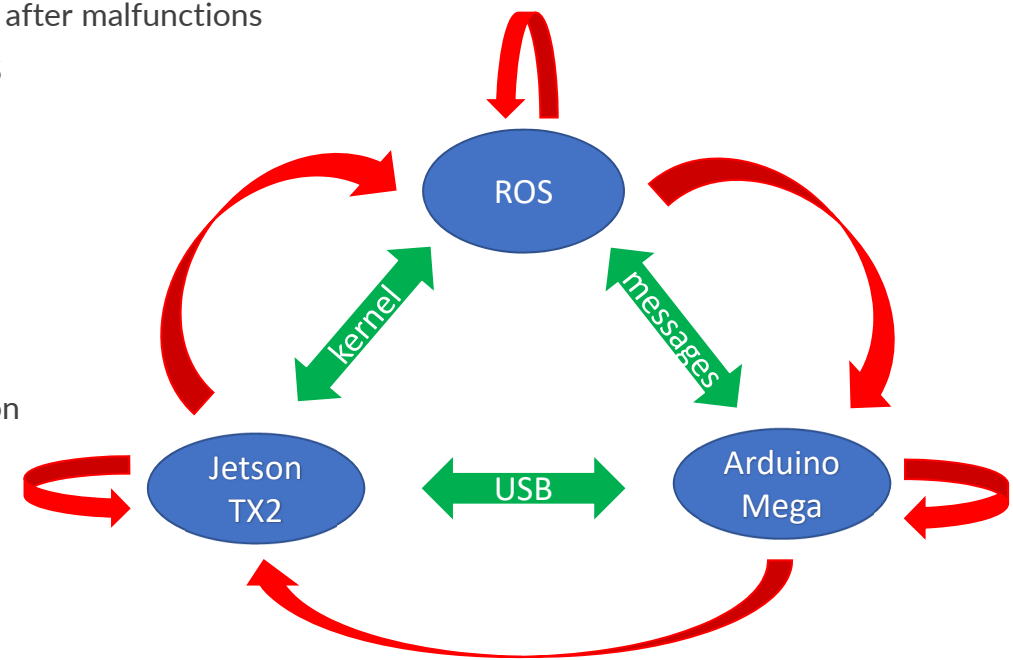
# Robot Software

- Ubuntu running ROS (Robot Operating System)
  - Open-source software
- Suite of ROS packages
  - Simultaneous Localization and Mapping (SLAM)
    - 2D LiDAR
  - Advanced Monte Carlo Localization (AMCL)
    - 2D LiDAR + Map
  - Extended Kalman Filter (EKF)
    - odometry + IMU + input commands
  - Voxel grid obstacle tracking
    - Ultrasonic + 3D LiDAR
- Remote control over Wifi



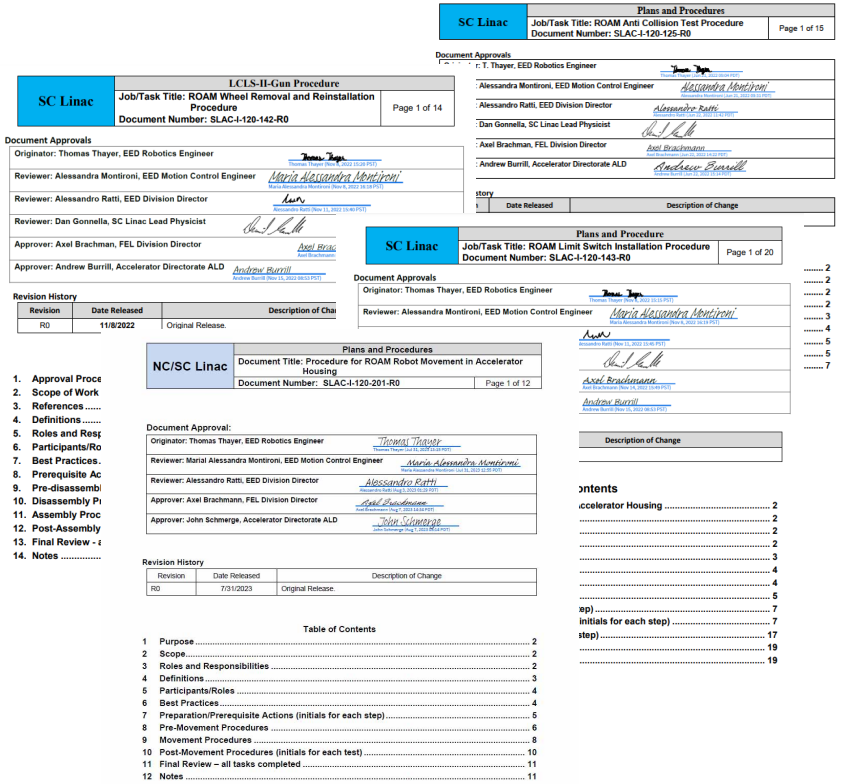
# Accelerator Specific Programming

- Three watchdogs to keep software running after malfunctions
  - Daemon process watching Ubuntu OS
    - Restarts Jetson TX2
    - Restarts ROS
  - ROS watching robot software nodes
    - Restarts ROS nodes
    - Restarts Arduino
  - Arduino watching serial communication
    - Restarts Arduino
    - Restarts Jetson TX2



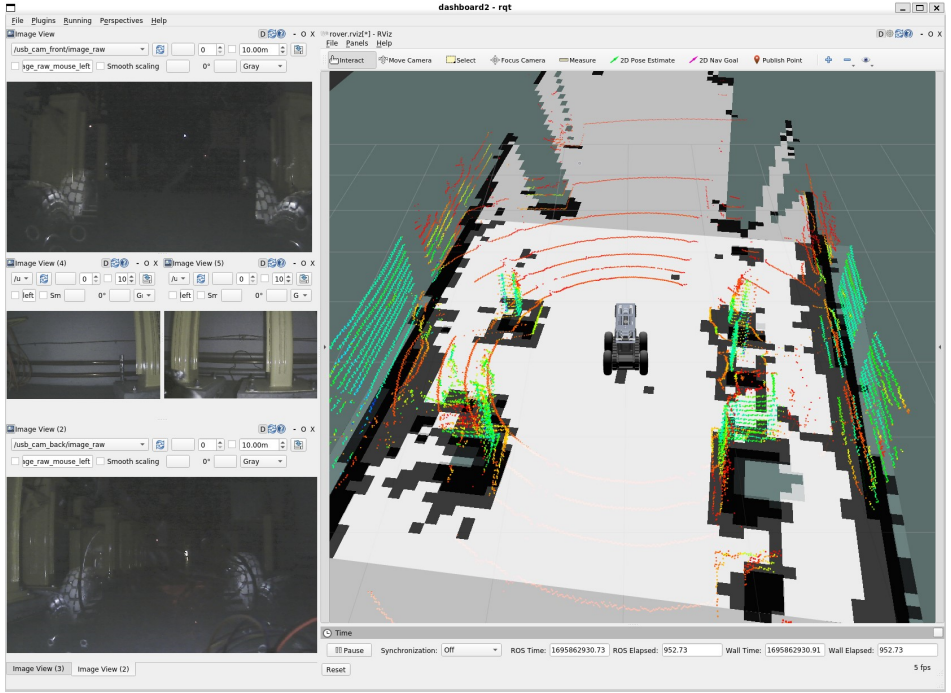
# Deployment Authorizations

- Deploying a robot to accelerator enclosures is a new process at SLAC
- Follow established Work Planning and Control Standards
  - Operators training
  - Area manager approval
  - Field checkout and recording of results
- Officially released checkout procedures
  - ROAM Anti Collision Test Procedure
  - Procedure for ROAM Robot Movement in Accelerator Housing
  - ROAM Wheel Removal and Installation Procedure
  - ROAM Limit Switch Installation Procedure



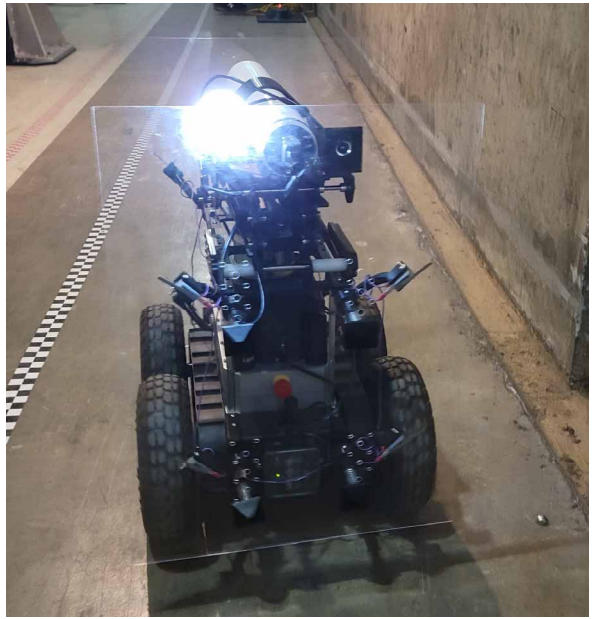
# Technical Complications

- Wireless networking
  - Sparse coverage within accelerator housing
  - High latency and interference
  - Access points susceptible to radiation
  - Extra/redundant access points needed across accelerator
- Driving difficulties
  - Reduced visibilities due to glare/reflections from robot headlights
  - Lack of unique landmarks makes judging distances and location difficult
- Hardware disruption
  - Frequent malfunctions fixed by watchdogs
  - Unknown if caused by radiation



# Conclusions and Future Work

- Rover prototype platform using COTS components
- Flexible sensor payload
- Tested in accelerator housing and support buildings
- Deployment within SLAC WPC boundaries
- Future goals
  - Integrate more sensors for monitoring
  - Second ROAM robot deployment
  - QR code based navigation of accelerator housing
  - Autonomous navigation with optimally safe trajectories



# The End

THANK YOU!

QUESTIONS?

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