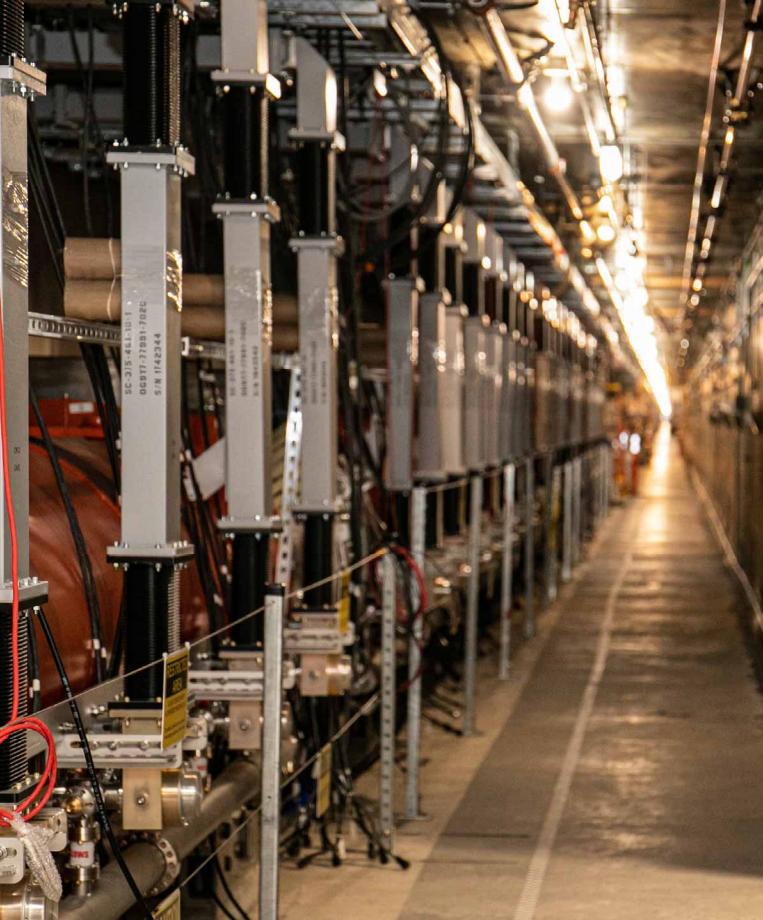


Deployment and Operation of the Remotely Operated Accelerator Monitor (ROAM) Robot

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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

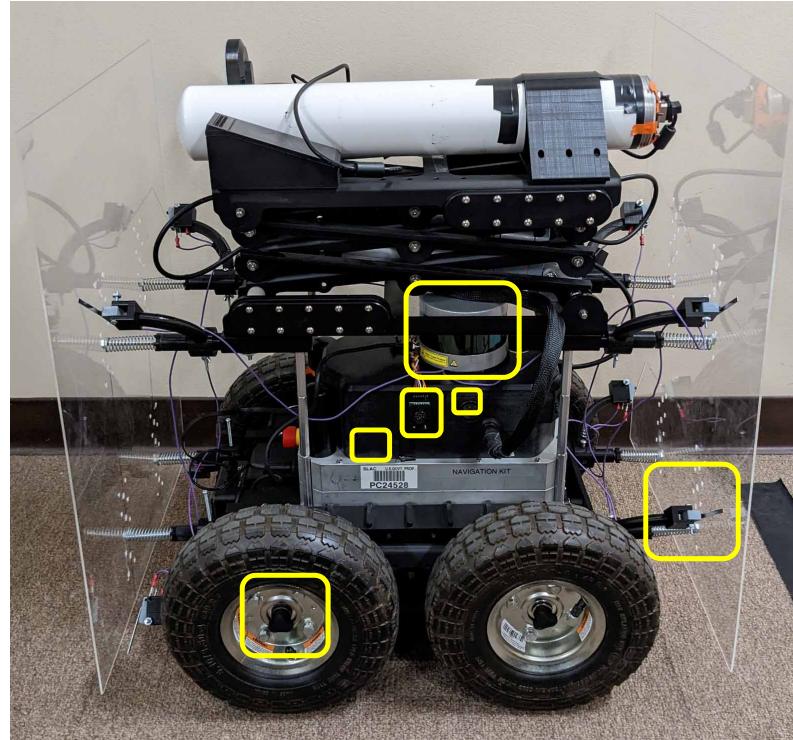
ROAM Overview

- 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



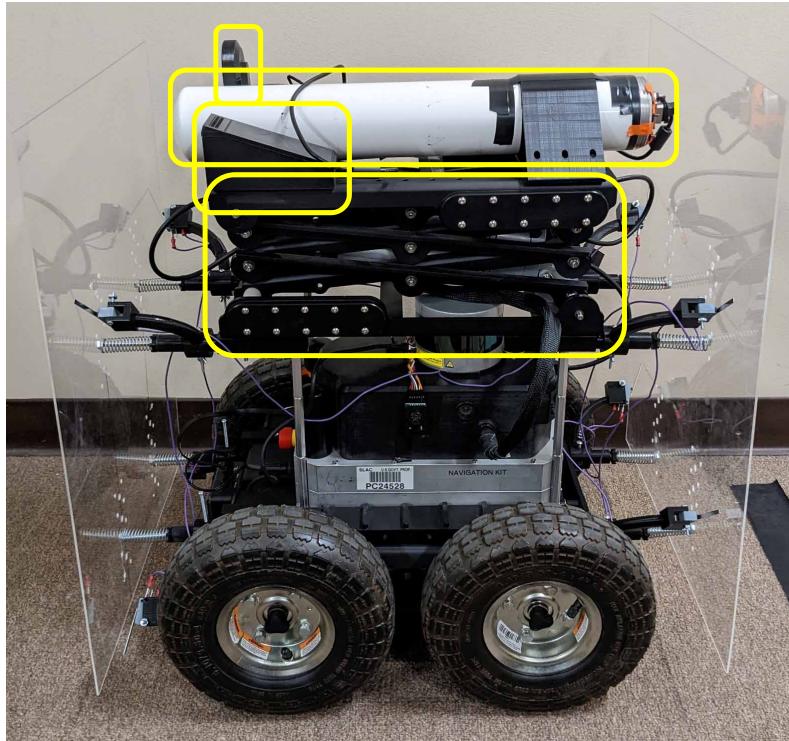
Robot Hardware

- 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



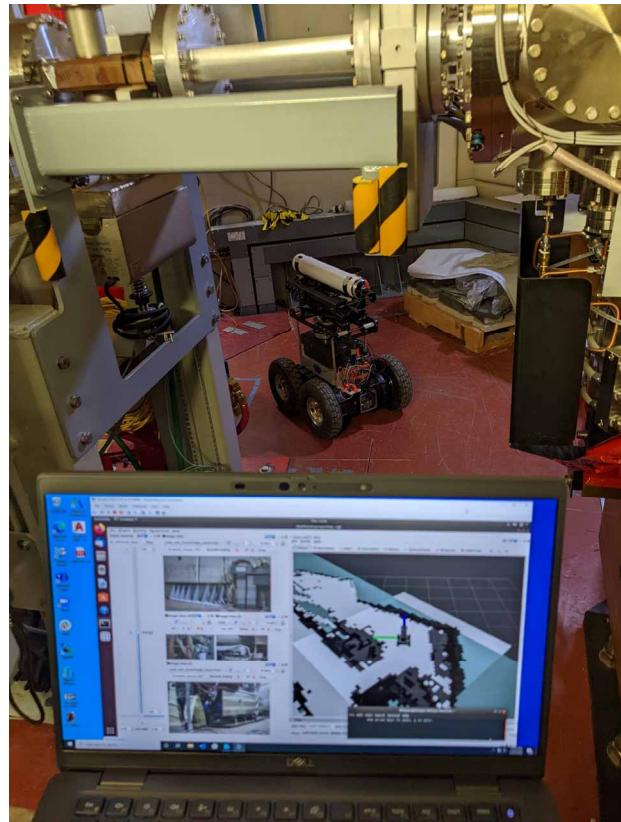
Configurable sensor platform

- 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*



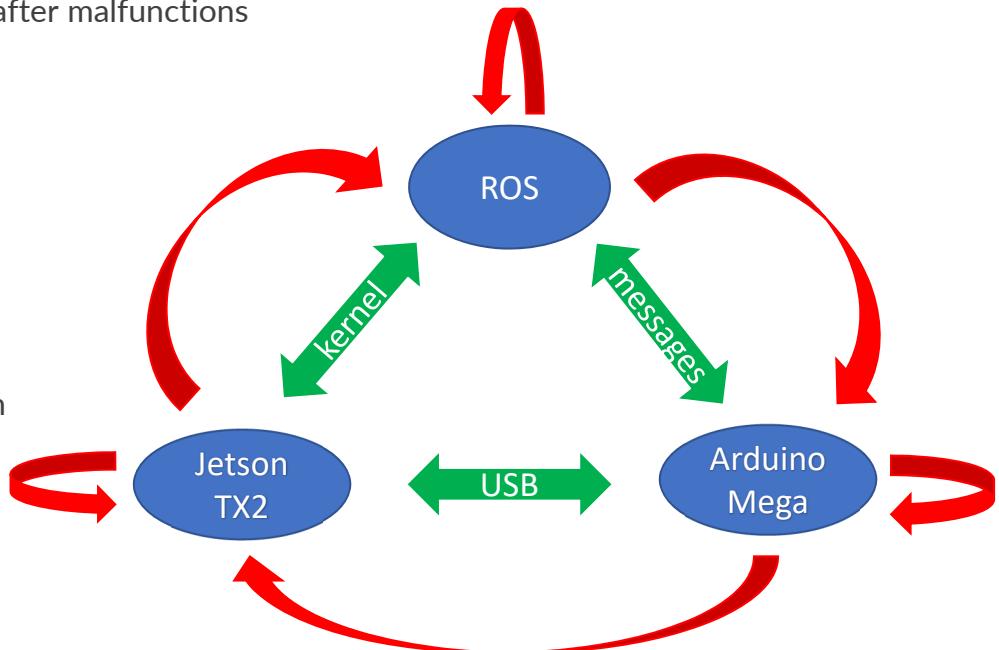
Robot Software

- 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



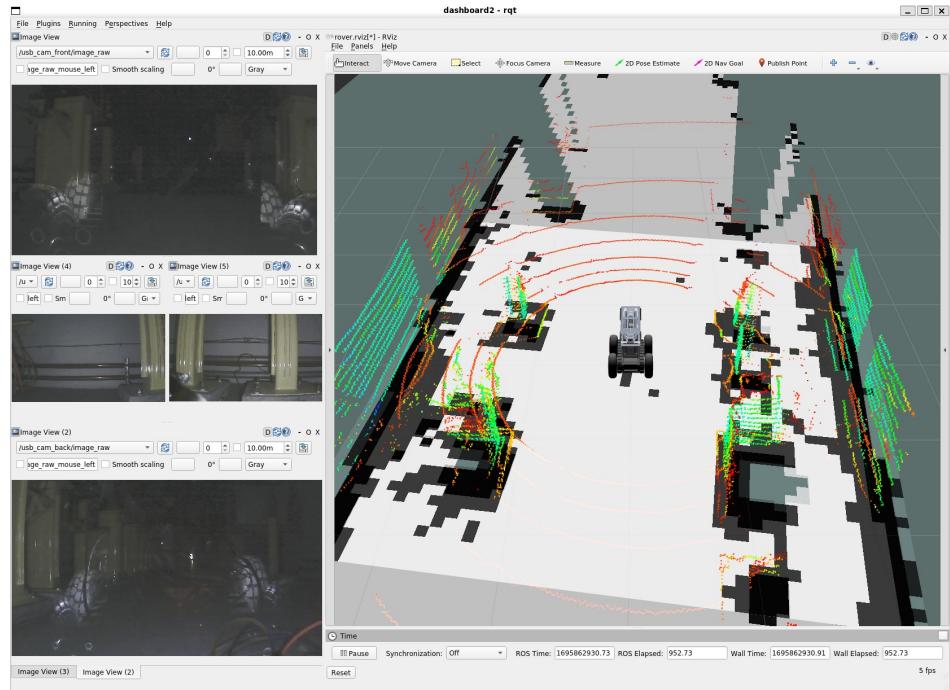
Deployment Authorizations

- 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

SC Linac	Plans and Procedures	
Job/Task Title: ROAM Wheel Removal and Reinstalation Procedure		
Document Number: SLAC-I-120-142-R0		
Page 1 of 14		
Document Approvals		
Originator: Thomas Thayer, EED Robotics Engineer <i>Thomas Thayer</i> Thomas Thayer Rev 0, 2022-08-10 (00:00:00)		
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story		
Date Released	Description of Change	
SC Linac	Plans and Procedure	
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Revision History		
Revision	Date Released	Description of Change
R0	11/8/2022	Original Release.
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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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