Optimizing Radiation-Hardened Memory for Autonomous Moon Rover Navigation

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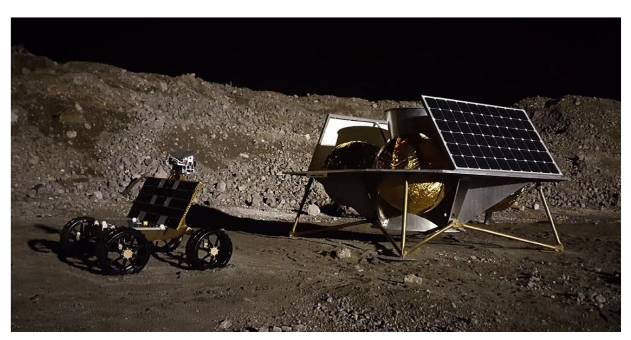
Overview

- The MoonRanger team will launch an autonomous rover to the Moon in 2022 to search for ice within lunar craters
- The harsh environment of space presents tight memory constraints throughout the mission
- The rover's onboard electronics must be protected from space radiation it will be subjected to en route to the Moon
- On the lunar surface, the rover must navigate autonomously between waypoints via planning safe and cheap paths

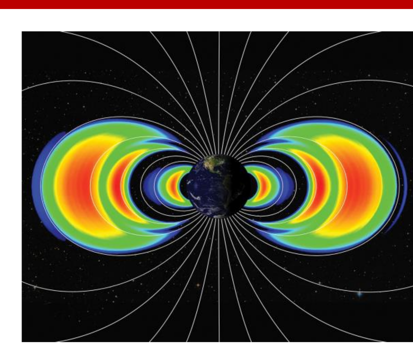
Research Objectives

- Identify radiation-hardening techniques for the onboard Nvidia Jetson TX2i that balance memory reduction with information preservation
- Investigate the structure of cost maps/functions for a memory-efficient path planner implementation



Background

Radiation Hardening



- Sources of Space Radiation[1]:
  - Galactic cosmic rays
  - Solar flare particles
  - Van Allen Belt particles (pictured)
- Radiation frequently threatens integrity of electronic equipment even in lower Earth orbit[1]
- Potential radiation-hardening solutions:
  - Hamming codes
    - Popular and simple error correcting code (ECC)
  - Triple modular redundancy (TMR)
    - Commonly used in space systems
  - Jetson TX2i onboard ECC (our default option)
- Each solution achieves varying degrees of error correction by generating redundant bits in memory

Cost Map-based Path Planning

- Cost maps store the traversability of the terrain surrounding the rover in memory
- Sensor data measures physical features of nearby terrain; can assign weights to observed slope and roughness to construct a cost map
- Planning algorithms can operate on top of cost maps to identify efficient paths

Discussion

Radiation Hardening Comparison

Rad-Hardening Technique	Hamming(72,64)[2]	TMR[3]	Onboard ECC[4]
Memory Reduction (%)	12.5%	66%	12.5%

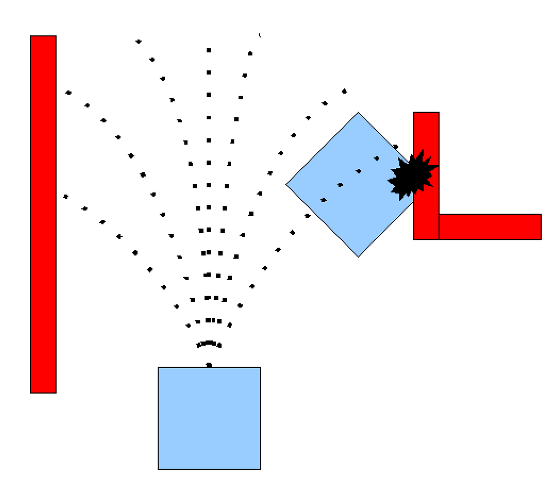
- TMR offers virtually total error correction via majority vote, though at great expense to compute power, as every data bit is triplicated
- Hamming(72,64) and the TX2i's onboard ECC both offer single error correction, double error detection (SECDED)
- Onboard ECC requires much less development overhead than implementing our own Hamming code

Cost Map-based Path Planning Algorithm Analysis

Cost maps are stored as grids to simplify computation by compromising with terrain resolution – however, cost maps that are too rigorous waste memory computing redundant regions the rover will never traverse

We examined several planners utilizing cost map inputs:

- *Probabilistic terrain analysis (PTA) algorithm*[5] applies statistical tests to cost map data to quickly compute likelihood of terrain traversability and resolve sensor errors collected from a moving vehicle
- *Cherif's two-level planner*[6,7] ignores terrain to construct global path but computes local paths in separate chunks by converting cost map to graph-search problem
- *Dynamic window approach (DWA)*[8] simulates brief forward motion on a set of arcs from the rover's current position in the cost map, selecting the cheapest path that brings the rover closer to its intended target



- DWA saves computational costs by only simulating select arcs while preserving cohesion of cost map data (local decisions still take global target into account)
- dwa_local_planner ROS package[8] within ROS navigation stack runs DWA algorithm on cost map input, constructing paths over cheap regions and avoiding high-cost obstacles; can potentially be integrated as-is to implement path planning within the final MoonRanger code

Conclusions & Future Work

- This study identifies efficient memory utilizations to mitigate radiation damage and navigation risks the MoonRanger rover will face throughout its mission
- The Nvidia Jetson TX2i's onboard ECC offers an effective compromise between sacrificing memory and correcting flipped bits[9], and its ease of use grants it a heavy advantage over implementing other common rad-hardening methods
  - The rover's mission range falls within lunar orbit, so the most likely radiation-caused defects are single event upsets[1], meaning SECDED will be sufficient
- DWA offers a promising preliminary planning algorithm due to its relative simplicity – effectively balancing planning capabilities with memory costs – as well as its wealth of existing ROS development and infrastructure
- Progress on isolating the DWA planner from the navigation stack and developing a demonstratable implementation was made – future work will explore making DWA compatible with existing autonomous software framework
- Next steps for radiation hardening involve verifying the correction capabilities of the TX2i's onboard ECC through direct radiation testing on the processor board

References

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