Developing Autonomous and Adaptive Systems For Space-Exploration Robotics With Neuromorphic Frameworks & Artificial Intelligence

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Q1: Research Question

ENGINEERING PROBLEM: Intricate Artificial Neural Networks are constrained due to resource, energy and radiation constraints, limiting full autonomy & adaptivity

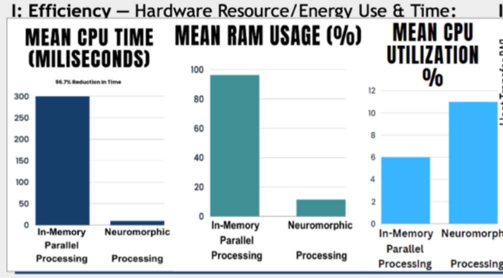
RESEARCH QUESTION: How can neuromorphic frameworks be adapted to integrate Spiking Neural Networks (SNNs) for Reinforcement Learning in space robotics, enabling low-power consumption, radiation resistance, and efficient real-time processing for autonomous & adaptive exploration?

Primary Endpoint: Balanced CPU & RAM Utilization (sub-30%), sub-20% noise effects, and structure withstands radiation.

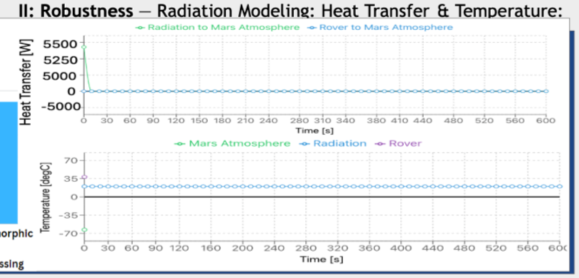
Secondary Endpoint: Adaptive decision-making, working within NASA Power of 10 Rules

Q3: Data Analysis and Results

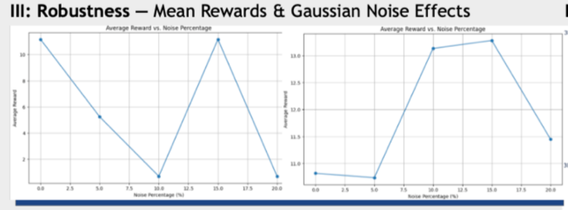
I: Efficiency – Hardware Resource/Energy Use & Time:



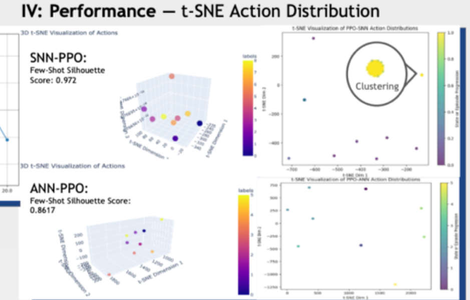
II: Robustness – Radiation Modeling: Heat Transfer & Temperature:



III: Robustness – Mean Rewards & Gaussian Noise Effects



IV: Performance – t-SNE Action Distribution

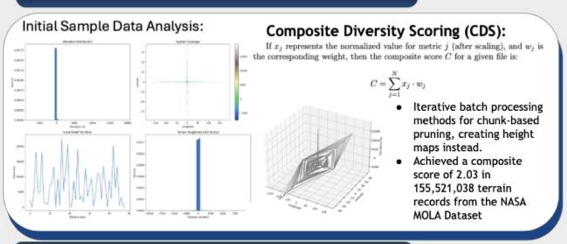


III: Welch's t-test of Silhouette Scores (Performance)

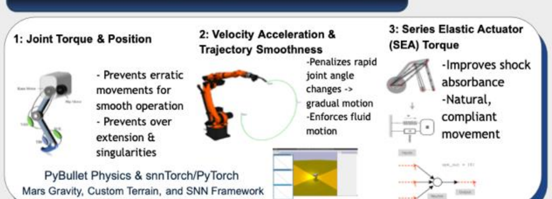
T-Statistic	P-Value	Standard T-Statistic & P-Values
-7.4427733	-0.00412273	p<0.01 – **Significant** t > 2 – **Significant**

Q2: Methodology/Project Design

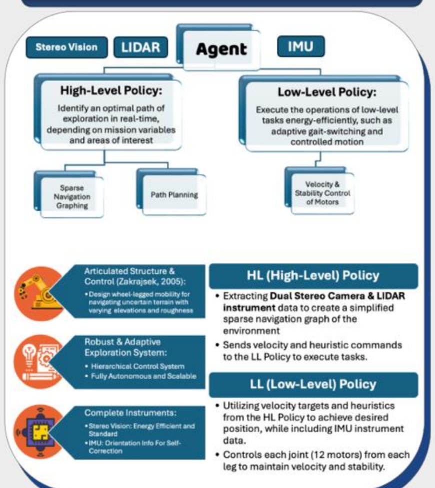
Methodology: Terrain Curation



Methodology: Agent Learning



Methodology: Agent Design



Robustness
Train model with varying Gaussian noise levels

Performance
Regularized to learn guide convergence

Efficiency
Constrain model with SBC hardware

Q4: Interpretation and Conclusions

- **Optimized Resource Usage**: Achieved 11% balanced RAM & CPU utilization with a 30× reduction in CPU time, enhancing efficiency.
- **Neuromorphic Computing Efficiency**: The model's efficiency mirrors the brain's data processing through time-dependent spikes and memory encodings (collocation).
- **Energy Efficiency**: The agent, running on a 5W Raspberry Pi 4B+, demonstrates significant energy efficiency compared to NASA's 110W Perseverance rover, suitable for constrained environments.
- **Robustness under Radiation**: Rover testing under Mars-like radiation conditions confirmed system stability, ensuring reliability for future missions.
- **Fault Tolerance**: Performance in incremental Gaussian noise tests showed greater fault tolerance, surpassing current AI tools on Perseverance.
- **Superior Adaptability**: t-SNE action distributions showed structured clustering in SNN-PPO, with faster policy adaptation (10-30 epochs). Silhouette scores (0.11 difference) and Welch's t-test ($t \approx \sim 7$, $p < 0.01$) confirmed SNN-PPO's superior decision-making under uncertainty.
- **Novel Solution for Future Missions**: This research offers a novel and effective solution to improve rover efficiency, robustness, and energy management for upcoming space missions.