Wander Rover: Autonomous AI-Driven Planetary Exploration with Fine-Tuned AI Language Models

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Cash funding needed: $95,000

AWS Promotional Credits needed: $40,000

Abstract

Space exploration faces a critical challenge: communication delays between three and forty-four minutes or longer between Earth and Mars prevent real-time decision-making, severely limiting explorative mission effectiveness. The Wander Rover Project addresses this through an AI-driven autonomous rover that combines computer vision, generative AI, and fine-tuned language models to enable intelligent, real-time decision-making during communication blackouts. Researching breakthrough possibilities for fine-tuned AI language models for spacecraft control, this project develops a rover capable of autonomous navigation, adaptive problem-solving, and scientific prioritization of projects without Earth-based intervention. The project also integrates advanced robotics education leveraging University of California's multi-year successes with a Robotics Camp program, grant possibility of graduate students contributing to space rover R&D innovation while gaining hands-on experience in AI fine tuning, robotics, and space system challenges. This multidisciplinary approach advances space exploration capabilities, STEM workforce development and US AI education mandates.

Keywords: *autonomous rovers, AI large language models, AI in space, communication delays, planetary exploration, AI robotics, education, AI literacy, computer vision, generative AI, GIS, STEM*

Introduction

The Challenge: Current Mars rovers face critical operational constraints. NASA's Perseverance rover experiences round-trip communication delays, forcing vehicles to halt operation, signal disruptions, or failure when encountering unexpected obstacles reducing mission efficiency and waiting days for ground control to approve scientific investigations or brainstorm solutions.

The Breakthrough Opportunity: Recent research from MIT and NASA demonstrates that fine-tuned large language models show promise in controlling remote vehicles and solving challenges using minimal training data. Studies show LLMs fine-tuned with low-rank adaptation achieve higher accuracy in generating creative solutions to challenging problems utilizing deep neural network approaches applying generalization and reasoning compared to previous human only direction.

Our Innovation: The Wander Rover will apply cutting-edge AI techniques to create an autonomous planetary rover that operates independently during communication blackouts prioritizing tasks and possibilities while mitigating challenges. By integrating fine-tuned language models with computer vision and GIS mapping, the rover can autonomously survey its environment and prioritize scientific targets to execute complex mission tasks without human intervention. The system uses generative AI trained on planetary exploration scenarios to make context-aware decisions such as determining optimal paths, identifying geologically interesting features, and adapting to unexpected environmental challenges.

Educational Impact: The UCR Library Creat'R Lab and Robotics Lab have conducted two years of intensive, very successful Robotics Camps, training over 40 students in advanced robotics, computer vision, and AI. In 2025, students built autonomous vehicles using convolutional neural networks, achieving high engagement and inspiring many to pursue careers related to technology. This proven educational framework will enable graduate students to contribute to Wander Rover development while gaining expertise in space robotics The program simultaneously develops a new pipeline for learning advanced AI techniques and innovative research on ramps for the 21st century aerospace industry.

Methods

Phase 1: Rover Design & Prototyping (Months 1-2)

- Design rover chassis for multi-terrain operation using CAD software (Fusion 360)
- Rapid prototyping with PLA 3D printing for functional testing
- Stress testing under simulated Mars conditions (temperature, terrain roughness)
- Begin AWS infrastructure setup for cloud-based AI model training

Phase 2: AI Model Development & Fine-Tuning (Months 2-5)

- Develop fine-tuned AI language model for autonomous control using Amazon SageMaker
- Train AI model on rover position, velocity, terrain data, and control commands
- Implement efficient fine-tuning on consumer hardware
- Integrate computer vision (CNN) for real-time object recognition and terrain classification
- Create GIS-based world models using simulated planetary terrain data
- Develop prompt engineering framework for mission commands

Phase 3: Hardware Integration (Months 3-6)

- Fabricate final chassis components using 3D printing (SLA or SLS)
- Integrate LIDAR, cameras, and environmental sensors
- Install edge computing hardware for on-board AI inference
- Deploy AWS IoT Core for monitoring and remote updates
- Establish secure communication channels between rover and cloud infrastructure

Phase 4: Graduate Student Robotics Camp & Collaborative Development (Months 4-8)

- Develop and conduct intensive 8-week robotics camp for graduate students
- Students contribute to: AI model innovation, refinement, sensor integration, autonomous navigation algorithms
- Hands-on training in CAD, embedded systems, machine learning, and cloud computing
- Team-based development using Agile PM methodology with weekly iteration
- Students present MVP and findings at camp conclusion, contributing to technical reports

Phase 5: Field Testing & Validation (Months 7-10)

- Deploy rover in Mars-analog environment (desert terrain with varied topography)
- Test autonomous navigation with simulated communication delays (15-24 minute and longer, day or multi-day latency)
- Evaluate AI decision-making under challenging conditions (dust, obstacles, equipment failure)
- Measure performance: distance traveled, targets identified, power efficiency, mission success rate
- Iterative refinement based on field data collected via AWS cloud storage

Phase 6: Analysis & Dissemination (Months 11-12)

- Comprehensive data analysis of rover performance metrics
- Technical reports on fine-tuned LLM performance in real-world robotics
- Open-source release of AI models, training datasets, and rover schematics
- Conference presentations at robotics and aerospace venues

Expected Results

- Functional autonomous rover prototype
- Fine-tuned language model achieving less than 15% error in control of navigation tasks
- Computer vision system with greater than 80% accuracy in terrain classification and scientific target identification
- Publication on LLM fine-tuning for autonomous robotics and AI education
- Open-source codebase and datasets hosted on GitHub and Hugging Face
- Graduate student cohort trained in advanced robotics and AI for space applications
- Technical documentation and educational AI robotics curricula suitable for educational institutions

Funds Needed

Cash Funding ($95,000):

- Mechanical design and fabrication: $55,000 (chassis materials, 3D printing, assembly)
- Sensors and electronics: $15,000 (LIDAR, cameras, microcontrollers, power systems)
- Edge computing hardware: $10,000 (AI inference processors, onboard computing)
- Testing and field deployment: $10,000 (travel, terrain simulation, data collection)
- Graduate student support: $5,000 (stipends for camp participation; support)

AWS Promotional Credits ($40,000):

- Amazon SageMaker: LLM fine-tuning, model training, optimization
- AWS Cloud Storage (S3): GIS data, telemetry logs, sensor outputs, training datasets
- AWS Lambda: Serverless execution for rover command processing and data analysis
- AWS IoT Core: Real-time telemetry, remote updates, secure device communication

Additional Information

What fundamental challenge does your research transform?

This project fundamentally transforms space exploration by eliminating dependence on Earth-based human control during communication blackouts and begins a program of autonomous self-reliance. This project also provides a paradigm shift in AI enhanced robotics education development and AI literacy towards US AI workforce and Robotics Education mandates. By applying recent breakthroughs in fine-tuned language models to autonomous robotics, we enable rovers to reason about complex scenarios, adapt to environmental changes, and execute multi-step mission objectives independently.

What makes this transformative rather than incremental?

Traditional rover autonomy relied historically on hard-coded rules that fail when encountering novel situations. Fine-tuned language models offer revolutionary transformative capabilities: they generalize across many possible scenarios, require minimal training data, and can be prompted with high-level natural language commands. This enables rovers to understand mission objectives contextually and develop adaptive strategies for many unexpected situations. The combination of LLMs with robotics and computer vision creates an intelligent decision-making system capable of scientific reasoning, deep research priority assessment, and creative problem-solving in unpredictable environments transformative for space exploration

Why now?

Three converging developments make this timely: (1) New Deep Research and Reasoning Models; (2) Planned lunar Mars missions require new rover autonomy; (3) Robotics + AI + Space provide amazing possibilities for solutions to previously intractable problems. AI infrastructure (AI fine-tuning tools, edge computing hardware, cloud platforms) has matured sufficiently to make this approach practically deployable and in need of an educated workforce and training on ramps.

Key risks and mitigation:

- Risk: AI hallucination leading to unideal commands. Mitigation: Multi-layer safety validation, ground truth, physics-based and human override protocols.
- Risk: Extreme environment hardware failures. Mitigation: Extensive stress testing and Mars-analog desert field trials before real-world deployment.
- Risk: Model failure in constrained training scenarios. Mitigation: Diverse training data including edge cases and continuous learning from field data.

Potential applications to Amazon:

- AWS space infrastructure: Fine-tuned models for satellite management and autonomous spacecraft control
- Amazon Robotics: Autonomous navigation algorithms for warehouse robots operating in dynamic or human sparse environments
- Blue Origin missions: Lunar landers and orbital vehicles requiring autonomous operation during communication delays
- Last-mile delivery: Adaptive trained datasets for autonomous delivery systems in unpredictable conditions

Team Expertise

The UCR Library Creat'R Lab and Robotics Lab brings proven expertise in advanced robotics education and technology development. The team has successfully delivered:

- Two consecutive years of intensive Robotics Camps training in CNN integration, autonomous AI systems, GIS, Data Science, AI and CAD (2 Ph.D.'s 3 Masters Degrees 75 years aggregated current specialized workforce density)
- Computer Engineering and Data Science Graduate students with high innovation
- Developed robotics curriculum and experience including 3D modeling, C++/Python programming, AI Deep Research, LLM's electrical circuitry, and AI model training
- State-of-the-art makerspace and robotics lab with metal 3D printers, laser engraving, and electronics fabrication
- Proven track record developing autonomous robots using computer vision and machine learning through years of hands-on experience with previous longer robotics summer workshops and several degrees

The PI and Co-PIs have demonstrated excellence in interdisciplinary collaboration, IT project management and combine robotics engineering, AI development, educational curricular innovation, and community engagement—creating an ideal team to deliver a transformative space robotics research while training the next generation of aerospace engineers for new millennia possibilities.

Appendix A - Technical References for Research Foundations in AI, Robotics and Mars Exploration

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Appendix B – Team Overview

RAYMOND UZWYSHYN, Ph.D. MBA MLIS

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EDUCATION

- Ph.D. Media Studies, New York University, 2000
- MBA Information Technology Project Management, American Public University, 2014
- MLIS Library & Information Science, University of Western Ontario, 2003

EXPERIENCE

Acting AUL for Research and Technology, UC Riverside (2024–Present):
Strategic leadership for AI initiatives, digital scholarship, GIS robotics, AI and makerspace labs.
Research Impact Coordinator/Full Professor, Texas State & MSU (2014–2024):
Pioneered AI R&D (Image Classification) 2019-2022. Established Statewide Texas State research data repository, 3D printing lab facilities, and various maker spaces across three universities.

PROFESSIONAL POSITIONS

2024-Present	Acting AUL Research & Technology / Director Research Services, UC Riverside
2022-2024	Research Impact Coordinator (Full Professor), Mississippi State University
2014-2022	Director, Digital, Web and Collections Services, Texas State University
2012-2017	Director, Online Libraries & eLearning, American Public University System
2009-2012	Head, Digital & Learning Technologies, University of West Florida

SELECTED PUBLICATIONS

1. Uzwyshyn, R. et al (Eds.). (2025). New Horizons in AI for Libraries. IFLA/De Gruyter
2.. Uzwyshyn, R. (2023). "Can We Get Some Agile Here? The Application of Agile Management Principles for IT Project Teams." *IFLA Trends and Issues in Library Technology*.
3. Uzwyshyn, R. (2020). "Developing a Digital Scholarship Ecosystem." *Proceedings of ICEIT*, St. Anne's College, Oxford University, UK.
4. Uzwyshyn, R. (2016). "Online Research Data Repositories: The What, When, Why and How." *Computers in Libraries*, 36(3), 18-24.
5, Uzwyshyn, R. (2015). One Size May Not Fit All: 3D Printers for Academic Environments. Computers in Libraries, 35(10), 4-8.

RELEVANT GRANT EXPERIENCE & AWARDS

- IFLA Dynamic Unit Award for Quality Impact of Work, IT Section (2024-2025)
- Transforming and Recycling 3D Printer Material Waste into Sustainable Solutions (2025) - Co-PI, $125K
- Campus Technology 2021 Impact Award for Digital Research Infrastructure Systems
- Bill & Melinda Gates Foundation Global Libraries Technology Reviewer (2008-2011)

ACTIVITIES

- UCR AI workshops: "Harnessing AI: Large Language Models for Research" (3/2025): AI Deep Research and Reasoning Models (5/2025), AI Assisted Coding for Research (11/ 2025)
- Chair, ASIS&T Information Visualization Special Interest Group
- Editor, IFLA IT Section Trends and Issues in Library Technology
- Member, UC Riverside AI Research and Education Institute (Raise@UCR)

RESEARCH INTERESTS

AI & Large Language Models | Research Data Infrastructure | Robotics, Maker, Multimedia and AI Labs| AI Literacy and Education | AI Deep Research/Reasoning Models| Research Libraries

Team Members and Roles

Dr. Raymond Uzwyshyn *Director of Research and Technology, University of California, Riverside* **Role:** Principal Investigator – Oversees AI systems integration, research coordination, and strategic direction. **Expertise:** AI systems architecture, grant leadership, interdisciplinary innovation, digital infrastructure, and team mentorship.

Dr. Barbara Martinez Neda *Research Data Scientist, University of California, Riverside* **Role:** Co-PI – Leads data modeling, AI fine-tuning, and performance analysis. **Expertise:** Machine learning, large language models, autonomous systems, python, computer science, and team mentorship.

Brendon Wheeler *Maker Services Coordinator, UCR Creat'R Lab* **Role:** Co-PI – Oversees hardware prototyping, student training, and robotics camp coordination. **Expertise:** CAD design, 3D printing, embedded systems, robotics education, Python/C++, and team mentorship. **Note:** Led UCR Robotics Camps (2023–2025).

Alvaro Alvarez *Innovative Media Librarian, UCR* **Role:** Co-PI – Supports immersive media integration and educational content development. **Expertise:** CAD design, GIS-based learning modules, interactive media production, NSF STEM outreach, and media reference support.

Janet Reyes *Geospatial Systems Librarian, UCR* **Role:** Co-PI – Leads GIS modeling and terrain analysis for rover navigation. **Expertise:** Geospatial data systems, cartography, and GIS reference and support.