REU Research Proposal

Department of Computer Science, Missouri University of Science and Technology
April 2025

Project Title: AI-Augmented Path Planning for Miners Based on Sensor Battery Levels in Underground Mines Using Reinforcement Learning and Generative AI

1. Description of the Project

Underground mining environments are inherently hazardous, featuring complex networks of tunnels where miners navigate daily under conditions of poor visibility, high humidity, toxic gases, and absence of GPS. Sensors deployed within the mine pillars continuously monitor environmental factors and miner movements to enable safety mechanisms and emergency responses. However, these sensors operate on finite battery power and their longevity is crucial for continuous, reliable communication and monitoring.

Building upon prior work in predicting sensor battery levels using Reinforcement Learning (RL), this project aims to develop an intelligent miner path-planning framework that actively incorporates real-time battery health of sensor nodes. By integrating Deep Reinforcement Learning and Generative AI models, including Large Language Models (LLMs), the system will dynamically suggest optimal paths for miners that avoid areas with low-power sensors and prioritize routes that maintain high communication reliability.

Unlike traditional path-planning approaches that rely solely on geometric distance or static hazards, this system will be adaptive, context-aware, and anticipatory. It will leverage battery-level predictions, miner density, historical communication patterns, and scenario generation (using LLMs) for "what-if" simulations in emergencies.

This integrated approach ensures:

- Prolonged operational time of critical sensors,
- Enhanced miner safety through communication-aware routing,
- Reduced maintenance frequency and costs,

- Contextual, explainable path recommendations using LLM-generated narratives for miner-friendly interface.

Generative AI models will be explored for the following possible cases:

- Synthesizing possible emergency scenarios for proactive planning.
- Data augmentation for miner movement patterns in simulation environments.
- To solve some inherent problems in typical RL algorithms (slower convergence, large state and action spaces)

2. Tasks for the Project

2.1 Literature Review and State-of-the-Art Analysis

- Task 1.1: Conduct a comprehensive review of existing miner path-planning algorithms, with a focus on energy-aware and safety-critical environments.
- Task 1.2: Analyze current methods in battery level prediction, including PPO-LSTM, and identify integration points for path planning.
- Task 1.3: Study applications of Generative AI for decision explanation and simulation augmentation.

2.2 Algorithm Development for Path Planning

- Task 2.1: Identify gaps in current path-planning frameworks for underground mining, specifically related to sensor energy constraints.
- Task 2.2: Design a novel DRL-based algorithm that incorporates predicted battery levels, miner density, and emergency factors.
- Task 2.3: Simulate path planning under varied conditions, evaluating robustness and adaptability.

2.3 Integration of Generative AI for Simulation and Explanation

- Task 3.1: Use LLMs to simulate diverse miner movement and emergency scenarios to train and stress-test the RL model.
- Task 3.2: Generate human-readable explanations for route recommendations, aiding miners and operators.
- Task 3.3: Explore hybrid architectures combining RL policy outputs with LLM interpretability layers.

2.4 Dataset Creation and Enhancement (Auxiliary task)

- Task 4.1: Generate miner trajectory datasets and sensor status logs.
- Task 4.2: Apply data augmentation using synthetic trajectories and battery discharge curves.

2.5 Deep Reinforcement Learning Model Training

- Task 5.1: Design and train PPO-based or GRPO-based models for path planning.
- Task 5.2: Integrate temporal data (via LSTM or Transformer-based architectures) for better sequential decision-making.
- Task 5.3: Validate models on both normal operation and simulated emergency scenarios.

2.6 System Integration and Testing

- Task 6.1: Build an integrated framework combining RL path planning, battery prediction, and LLM-based explanation modules.
- Task 6.2: Test in simulated underground environments, measuring accuracy, safety, and efficiency.
- Task 6.3: Iterate based on performance feedback, improving decision latency and reliability.

2.7 Documentation and Dissemination

- Task 7.1: Document design choices, experiments, and system architecture.
- Task 7.2: Prepare academic papers for submission to leading conferences in AI, sensor networks, and mining safety.
- Task 7.3: Develop technical presentations and demos for broader dissemination.

3. Required Skills and Abilities

- Proficiency in Python programming.
- Experience with Reinforcement Learning frameworks (e.g., Stable Baselines3, RLlib) (Preferred)
- Knowledge of neural networks
- Competence in data simulation and augmentation techniques.
- Familiarity with underground mine sensor networks (preferred but not mandatory).

- Analytical skills to interpret complex simulation results.
- Ability to document and explain AI decisions clearly for non-technical users.

4. Materials to Study

- Manish Anand Yadav et al., "Predicting Battery Levels of Sensor Nodes Using Reinforcement Learning in Harsh Underground Mining Environments," ACM SAC 2025. (Draft of the paper will be sent. This paper will be available online soon)
- Goyal, Abhay, Sanjay Madria, and Samuel Frimpong. "MinerFinder: A GAE-LSTM method for predicting location of miners in underground mines." Proceedings of the 30th International Conference on Advances in Geographic Information Systems. 2022.
- Related works from references in the above papers (or any other papers), especially:
    - RL-based charger path planning in sensor networks.
    - DRL algorithms for wireless energy harvesting networks.
- Survey papers on Generative AI for simulation and safety-critical environments.
- Simulation tools such as OpenAI Gym for environment modeling.