PROJECT NAME

PROJECT LEAD

PROJECT MANAGER

ABSTRACT

The "Adaptive Autonomous Mining Decision System (AAMDS)" is an advanced architectural framework designed to automate and optimize In-Situ Resource Utilization (ISRU) operations in deep-space environments. Space exploration is fundamentally limited by the high costs and logistical risks of transporting materials from Earth; therefore, harvesting local resources is a necessity for long-term sustainability. AAMDS addresses the core challenges of asteroid mining—such as extreme signal latency, micro-gravity instabilities, and unpredictable surface topographies—through an autonomous decision-support algorithm. By integrating Multi-Sensor Fusion and a specialized Objective Function (J), the system performs real-time risk assessment and energy optimization. This ensures mission continuity and hardware preservation even when communication with Earth is lost or delayed.

PROJECT AİMS

The primary goal of this project is to develop a self-governing system that minimizes human intervention and logistical dependence on Earth-based mission control.

- Autonomous Latency Mitigation: In deep space, signal delays range from seconds to several minutes. The objective is to enable the rover to "think" locally, making split-second decisions to avoid hazards without waiting for Earth-to-Space transmissions.
- Structural Integrity and Operational Survival: Asteroids have irregular surfaces and very low gravity. AAMDS aims to prevent the vehicle from tipping over or losing contact with the surface by monitoring stability in real-time and triggering active compensation mechanisms (e.g., micro-thrusters).
- Advanced Resource Management: Space missions operate on a razor-thin energy margin. The system aims to intelligently manage a limited 5 kWh energy budget, dynamically prioritizing tasks like excavation, stabilization, and data transmission to achieve the highest possible material yield (Y).
- Hardware Longevity through Intelligent Monitoring: By establishing a 40% risk threshold, the project seeks to eliminate "blind operations" that lead to motor burnout or mechanical failure, effectively protecting multi-million dollar space assets.

METHODOLOGY

The methodology is built upon a five-layer adaptive software architecture that processes environmental uncertainty into actionable mechanical commands.

1. Data Acquisition and Proprioceptive "Indirect Sensing"

A major technical challenge in space robotics is the lack of specialized sensors for extraterrestrial soil resistance. AAMDS solves this by using the robot's own internal state as a sensor (Indirect Sensing):

- Current-Based Torque Analysis: The system monitors the electrical current (I) drawn by the excavation motors using Hall-effect sensors (e.g., ACS712). Since motor torque is directly proportional to current, any spike in I is interpreted as an encounter with high-density regolith or a buried obstacle.
- Force Feedback Integration: Force Sensitive Resistors (FSR) are placed on the landing gears and the drill assembly. These sensors measure the "reaction force" from the surface. In low

gravity, this data is critical to prevent the rover from "launching" itself off the asteroid during high-pressure drilling.

- Inertial Measurement (IMU) Fusion: A 9-axis IMU tracks the center of gravity. If the tilt angle exceeds safety limits during a dig, the system immediately recalculates the torque output or activates stabilizing thrusters to maintain balance.

2. Risk Calculation and Normalization Framework

Data from disparate sensors (Amperes, Degrees, Newtons) are normalized into a 0-1 scale to be processed mathematically. A predictive Risk Score (R) is then generated using a weighted formula:$R = w_1 S + w_2 U + w_3 F$

Where S represents surface stability, U represents system health/energy status, and F represents force equilibrium. This score allows the system to quantify "danger" before it manifests as a physical failure.

3. Decision Engine (The AI Core)

The intelligence of AAMDS is governed by a multi-parameter Objective Function:$J = Y - \alpha E - \beta R$

The algorithm calculates J for multiple possible actions (e.g., Continue Digging, Relocate, Standby/Recharge) and selects the path that provides the highest "Mission Value." If the battery is low, the coefficient α increases, forcing the system into an ultra-energy-saving mode. If the risk is high, β dominates the equation, prioritizing safety over yield.

4. Action Layer and Adaptive Feedback Loop

Once a decision is made, the Action Layer executes PWM (Pulse Width Modulation) commands to the motors and thrusters. A critical feature is the Feedback Loop: after every mechanical pulse, the sensors re-scan the environment. If the "soil resistance" changed after the first inch of drilling, the algorithm adapts the next second of the mission accordingly, ensuring the system remains truly adaptive.

EXPECTED RESULTS

High-Latency Resilience: Successful demonstration of a rover completing complex mining cycles with zero human input, overcoming simulated signal delays of over 10 seconds.

- Zero Hardware Loss (Safety): The 40% risk threshold is expected to prevent 100% of catastrophic failures (like motor burnout or tipping) in simulation environments.
- Mass-to-Intelligence Efficiency: Proving that software-based "Indirect Sensing" can replace heavy, specialized sensors, thereby reducing launch mass and mission costs.
- Scalable ISRU Infrastructure: Validating a software framework that can be scaled from small asteroid prospectors to large-scale Martian or Lunar water-ice harvesting operations.
- Increased Mission Life: By avoiding over-torquing and mechanical stress through real-time feedback, the operational lifespan of the rover is expected to increase by at least 30%.