

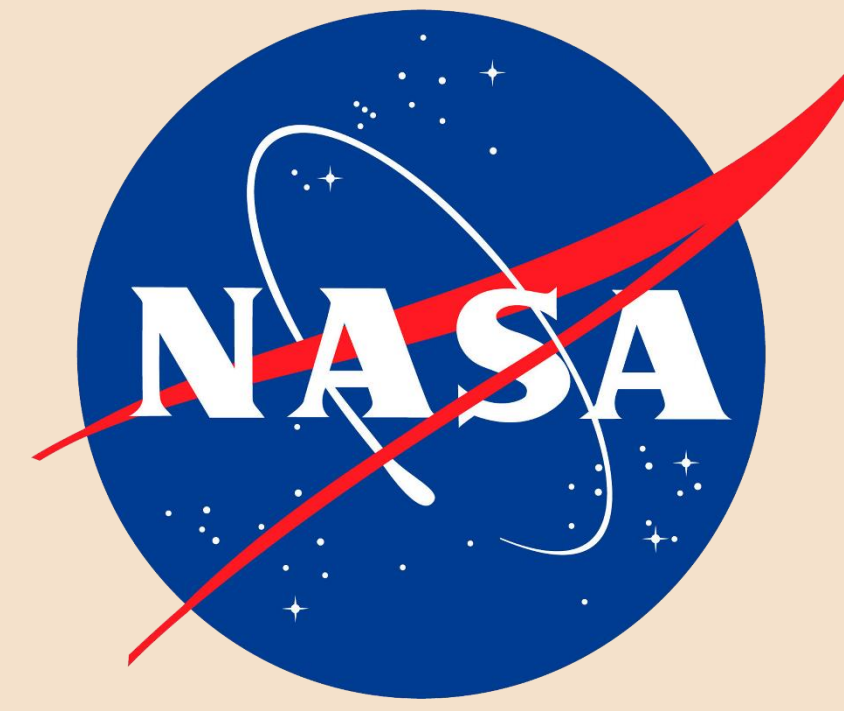
HARP Robotics Project

HEXAPODAL AUTONOMOUS ROVER for Extreme Terrain Navigation

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Abstract

This project presents the design and field testing of a hexapod autonomous rover developed to move in Mars-like terrain, including loose sand and uneven surfaces. The system integrates multi-legged locomotion, onboard sensing, and autonomous navigation capabilities. Field testing at the Great Sand Dunes demonstrated successful basic locomotion, while also revealing limitations in structural durability, sensor reliability, and full system integration. These results highlight key areas for improvement in future iterations of autonomous terrain exploration systems.

Introduction

Navigating uneven terrain, such as sand dunes, presents a significant challenge for traditional wheeled robotic systems. Hexapod locomotion offers improved stability and adaptability by maintaining continuous ground contact across multiple legs.

This project aims to develop an autonomous hexapod rover capable of moving across Mars-like terrain and collecting environmental data.

Objectives include:

- Designing a six-legged rover capable of stable movement on uneven terrain
- Implementing autonomous navigation for obstacle avoidance
- Integrating sensor systems for environmental perception and data collection

Design Principles

KEY SPECIFICATIONS

- **Weight:** 4.6 kg
- **Battery Life:** Estimated 3.25 hours
- **Sensors:** IMU, Time-of-Flight, Camera

• Tripod Gait Stability

Keeping three legs in contact with the ground at all times to help maintain stability

• Terrain-Adaptive Foot Design

Wide foot pads increase surface area and reduce sinkage in loose sand

• Bio-Inspired Locomotion

An Insect-inspired design improves movement over uneven terrain compared to wheeled systems

Perception & Autonomous Navigation

Combining multiple sensor inputs (IMU, Time-of-Flight, camera) supports obstacle detection and reactive navigation

Evaluation Criteria

Final performance will be evaluated based on:

- Terrain adaptability in loose sand
- Autonomous navigation accuracy
- Energy efficiency and runtime

Methodology

The hexapod rover system was designed with an integrated mechanical, electrical, and control architecture to enable locomotion across uneven terrain. The design consists of a six-legged structure activated by 18 servo motors and controlled by an onboard processing unit. Sensor inputs, including IMU and Time-of-Flight sensors, provide environmental awareness for navigation and stability.

Locomotion is achieved using a tripod gait, ensuring continuous ground contact and stability during movement. Predefined gait sequences control leg coordination, allowing forward motion across loose and uneven surfaces.

Field testing was conducted in a sand dune environment to evaluate system performance under realistic conditions. The rover was tested on its ability to traverse loose sand, maintain stability, and navigate obstacles, with observations recorded for system behavior and limitations.

Figure 1. System Architecture and Data Flow

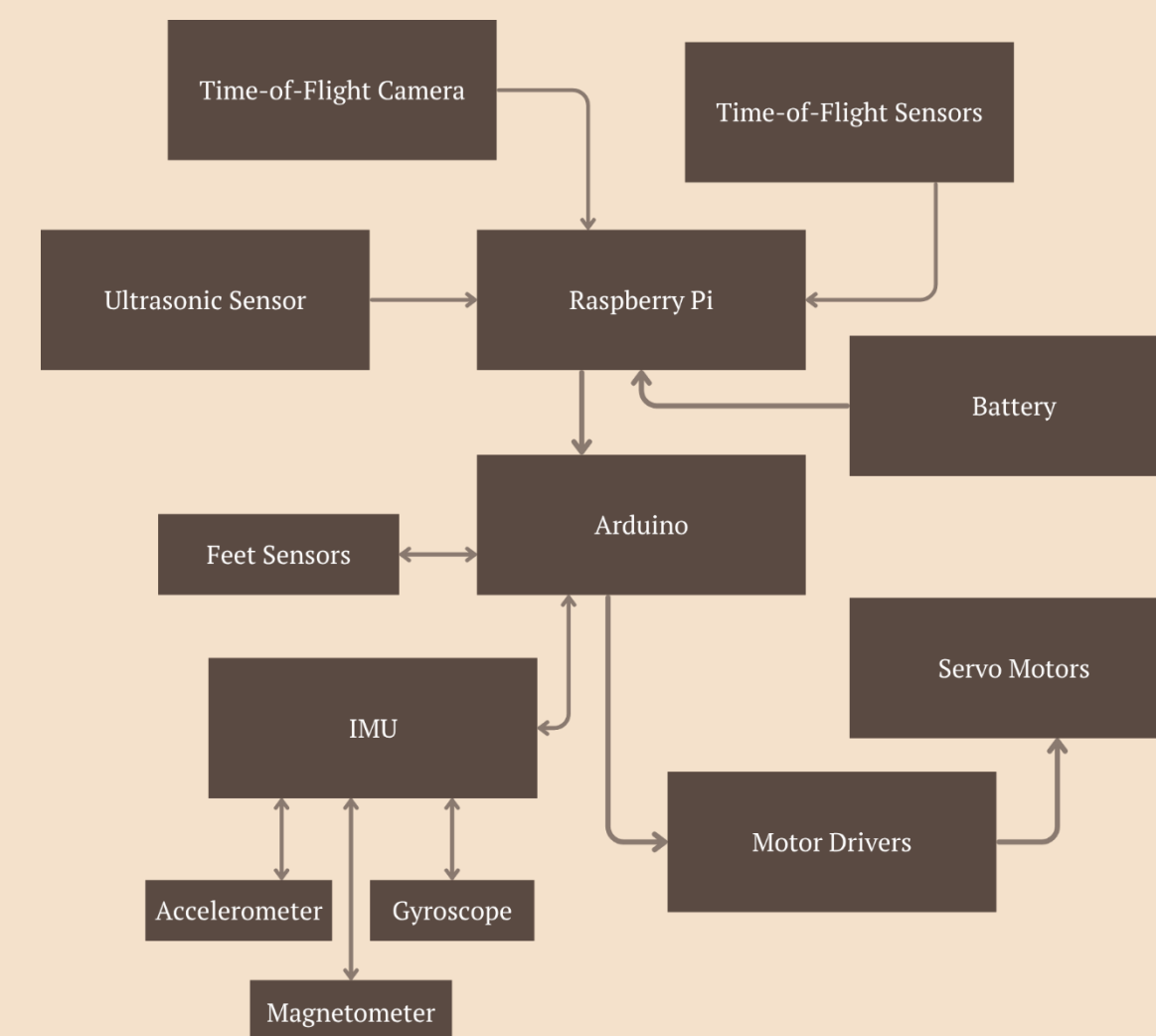
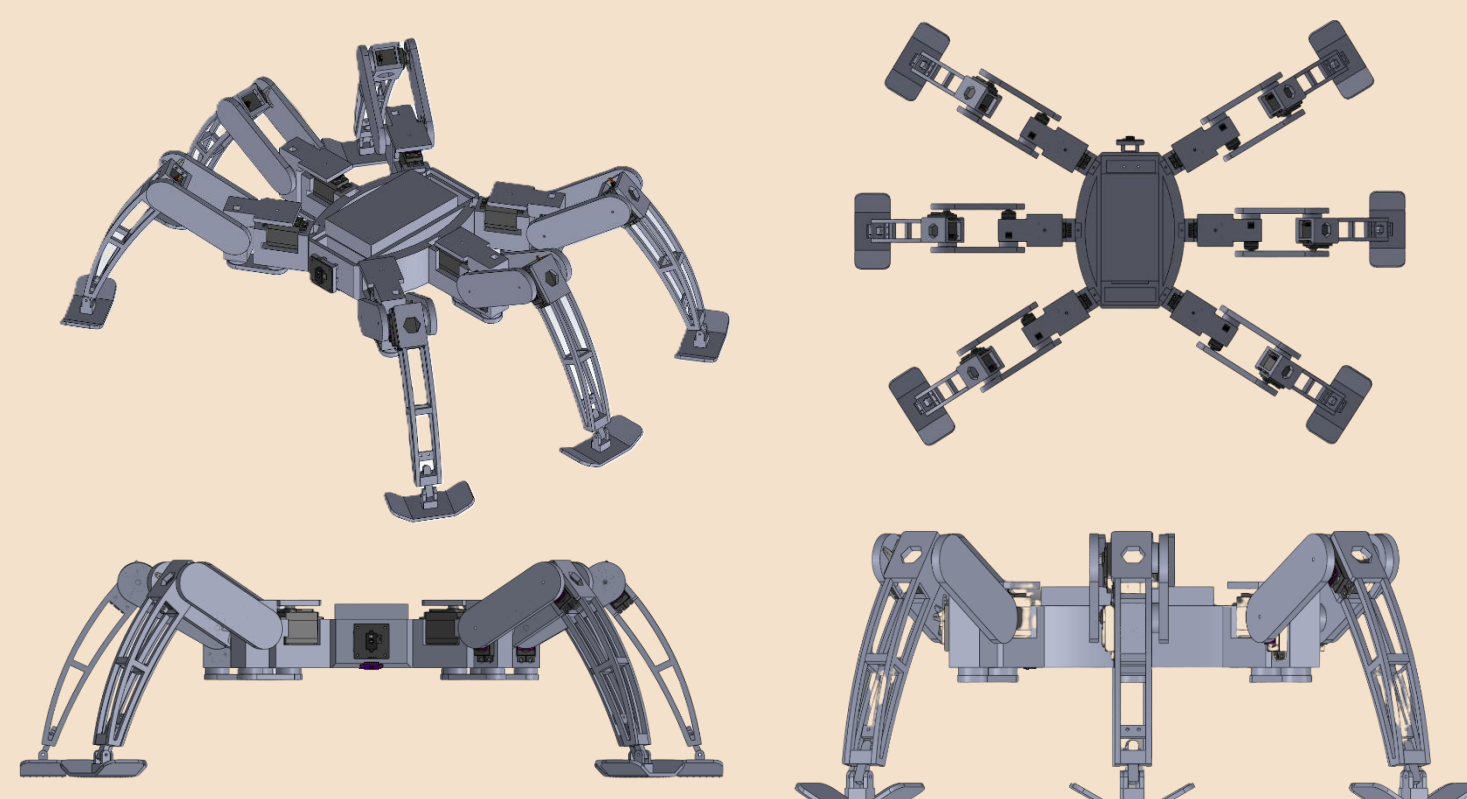


Figure 2. Final CAD Design of Hexapod Rover (Multi-View)



Field Testing Results

- The rover demonstrated successful walking on loose sand, maintaining basic stability and forward movement under initial test conditions.
- During obstacle testing, the rover demonstrated initial movement but showed inconsistent performance when navigating uneven terrain and changes in elevation.
- A structural failure occurred during testing, resulting in the loss of one leg, which significantly reduced mobility and prevented continued obstacle completion.
- Sensor systems were not reliably operational in the field environment, limiting the rover's ability to perform autonomous navigation and requiring manual control.
- Environmental conditions, including strong wind and shifting sand at the test site, introduced additional instability and variability in performance.
- Overall, testing validated basic locomotion capabilities while identifying key limitations in structural robustness, sensing reliability, and full system integration.

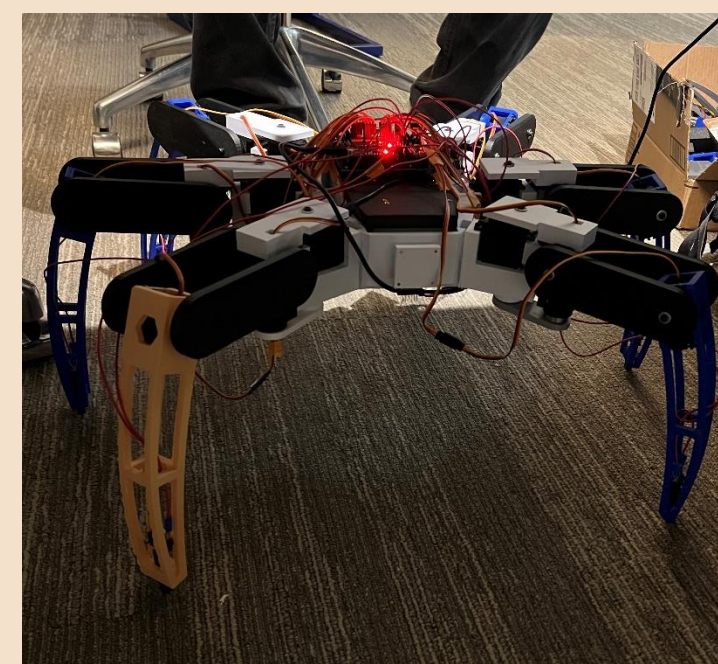


Figure 3. Preliminary Testing of Hexapod Rover Prior to Field Deployment

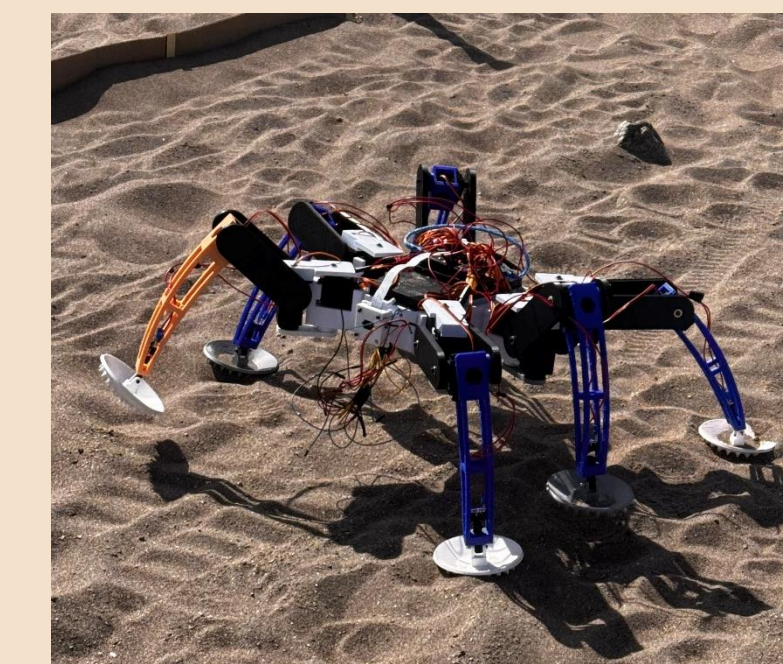


Figure 4. Rover Performance During Obstacle Navigation

Performance Summary

- Successfully demonstrated forward locomotion in loose sand
- Maintained stability using tripod gait under initial conditions
- Limited obstacle navigation capability due to control and sensing constraints
- Structural failure (leg) reduced mobility during testing
- Failed sensor systems did not support autonomous navigation

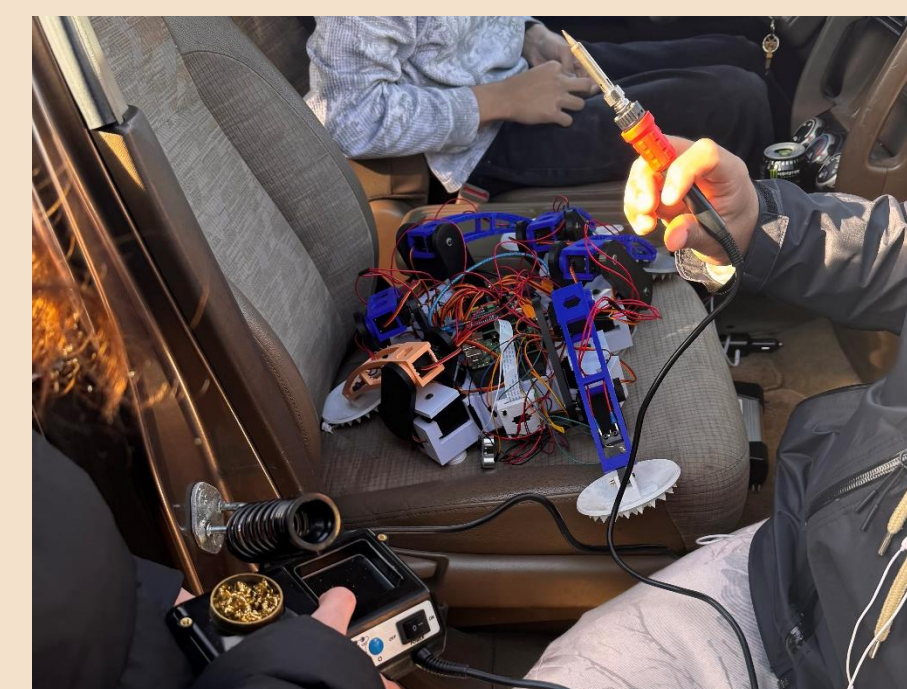


Figure 5. Field Repair and System Reconfiguration During Testing
On-site soldering and system adjustments were performed to address hardware failures and maintain operational capability during testing.

Conclusion

The hexapod rover successfully demonstrated basic locomotion in loose sand, validating the effectiveness of multi-legged mobility for uneven terrain. The tripod gait provided stability during initial movement, supporting the feasibility of the system's mechanical design.

However, field testing revealed key limitations in structural durability, sensor reliability, and overall system integration. A structural failure during testing reduced mobility, while lack of sensor performance limited autonomous navigation capabilities.

Future work will focus on improving structural robustness, refining sensor integration, and advancing control systems to enable more reliable and fully autonomous operation in complex environments.

Future Work

- Improve structural durability to prevent mechanical failure
- Enhance sensor reliability and integration for consistent data input
- Develop more advanced control algorithms for adaptive locomotion
- Implement autonomous navigation and obstacle avoidance
- Conduct additional field testing in varied terrain conditions

Engineering Applications

• Infrastructure Inspection

Alternative to drones for close-up inspection of critical structures

• Environmental Monitoring

Sensitive environments not suitable for wheeled robots

• Search & Rescue

Supports life-saving search and rescue efforts in hazardous environments

• Space Exploration

Mars/Moon rovers for unstructured, rocky and sandy terrain

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