Self-Balancing Rovers (BLNC)

TEXAS A&M UNIVERSITY Engineering

Project Lead: Jonathon Foltyn

Members: Aaron Bailey, Jaren Belda, Bryce Chuang, Keith Xavier Fernandez, Jacob Godfrey, Ryo Kato, Vin Nair, Caleb Snider, Sam Woravka, Renee Zhu

TEXAS A&M UNIVERSITY ROBOTICS TEAM & LEADERSHIP EXPERIENCE

Problem Definition

BLNC is focusing on developing rovers that can adjust the location of their center of gravity to maintain stability in extreme terrains. These rovers follow a two-wheeled inverted pendulum architecture.

V1 Rover

The V1 Rover is BLNC's two-wheeled inverted pendulum testbed to verify and test control systems. The rover is primarily 3D printed with certain mechanical components, such as standoffs and other hardware being COTS parts.

Design Specifications:

- Total mass: 1.45 kg
- CoM height: 20 cm from pivot point
- Wheels: 100 mm diameter
- 1:10 gear ratio between actuator and wheel
- Batteries and motors positioned high to raise the CoM as much as possible
- Material: PLA-CF (main body), PETG (wheel hubs)

With multiple iterations, the mechanical design of the rover was made to be strong against impacts while protecting critical electrical components. PLA-CF was chosen for the main body for increased durability and rigidity. The wheels were cast in silicon to increase friction with the ground, allowing the wheels to move reliably without slippage.

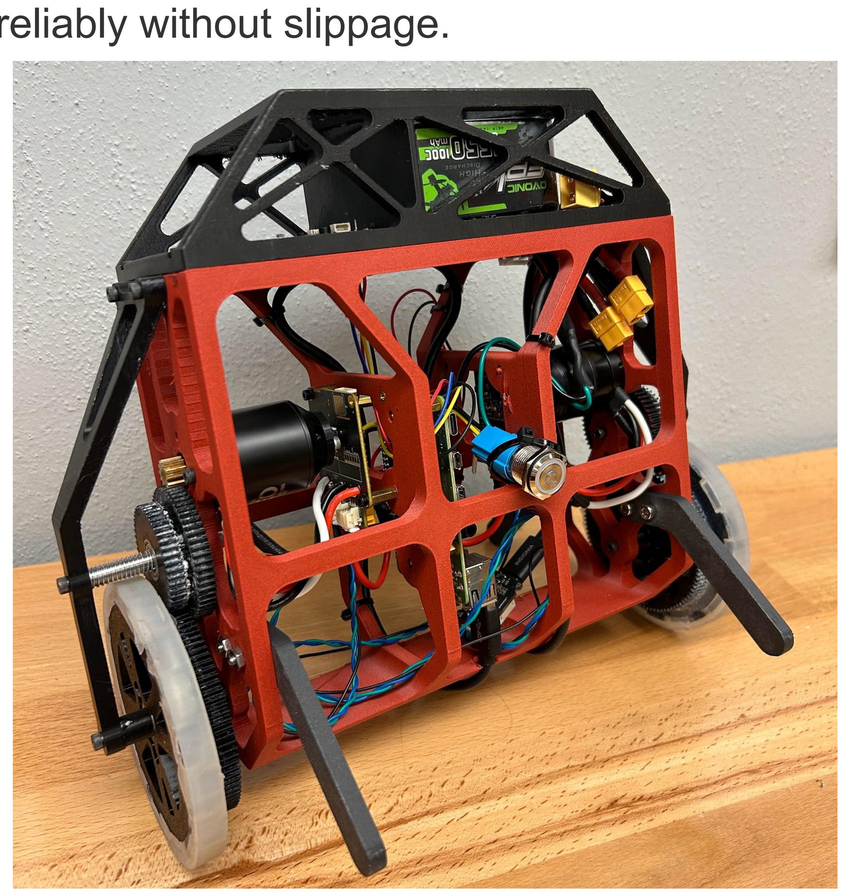

Figure 1. *V1 Rover Fully Assembled & Wired*

Electrical System

V1 Rover Electrical System:

Based on control-system analysis and the rover's operating requirements, we selected electrical components capable of supporting at least one hour of balancing operation. Under typical conditions, each motor produces max 2.5 N·m of torque, allowing the actuators to operate at approximately 60% effiiency.

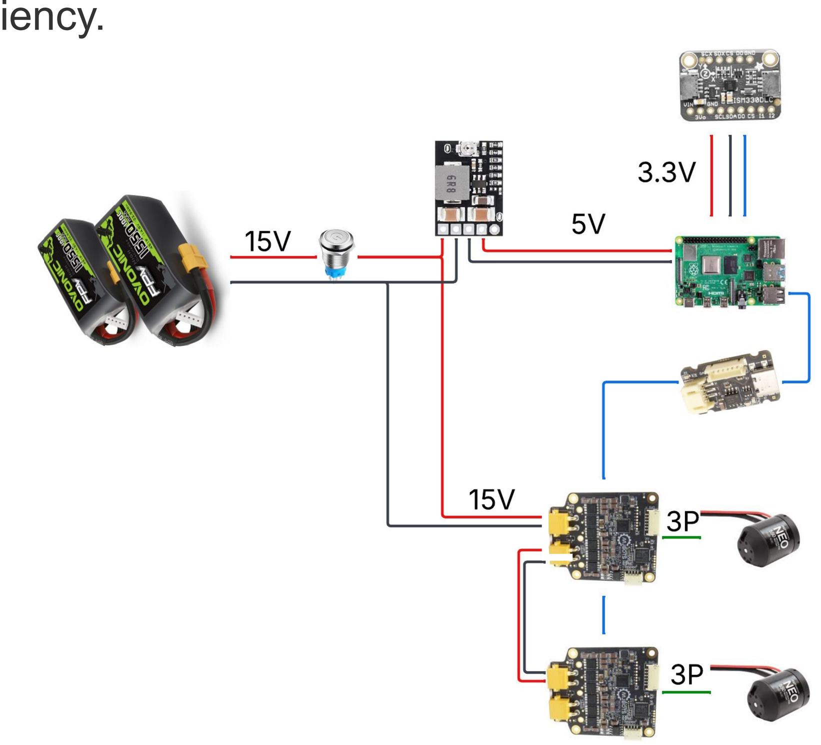

Figure 2. *Electrical Schematic for V1 Rover*

Simulations and Software

V1 Rover Simulation:

In order to test different control theories without harming the rover, a simulated test environment is being explored. We are using the IsaacSim environment and importing a URDF file from ROS2. This enables us to simulate rover movement on a CAD accurate rover model.

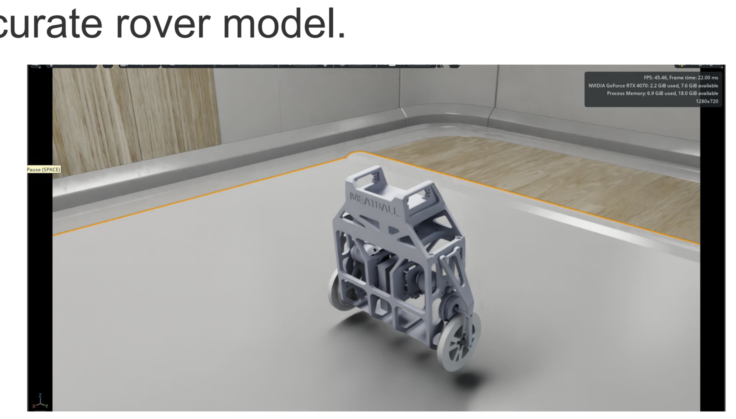

Figure 4. *V1 Rover in an Isaac Sim Environment*

V1 Rover Software:

The rover's main controller is a Raspberry Pi 4B and communicates with sensors via CANFD and I2C. All software is written in python. The motor controllers provide velocity, torque, and position data. An IMU provides angular data.

Controls

Traditional Control:

A cascade Proportional-Integral-Derivative (PID) controller is one of the control solutions we have developed. The outer loop of the controller determines the necessary pitch angle to move the rover to the desired position. The inner loop of the controller determines the necessary motor velocity to rotate the rover to the desired pitch angle. All 6 gains were manually tuned using the Ziegler–Nichols tuning method.

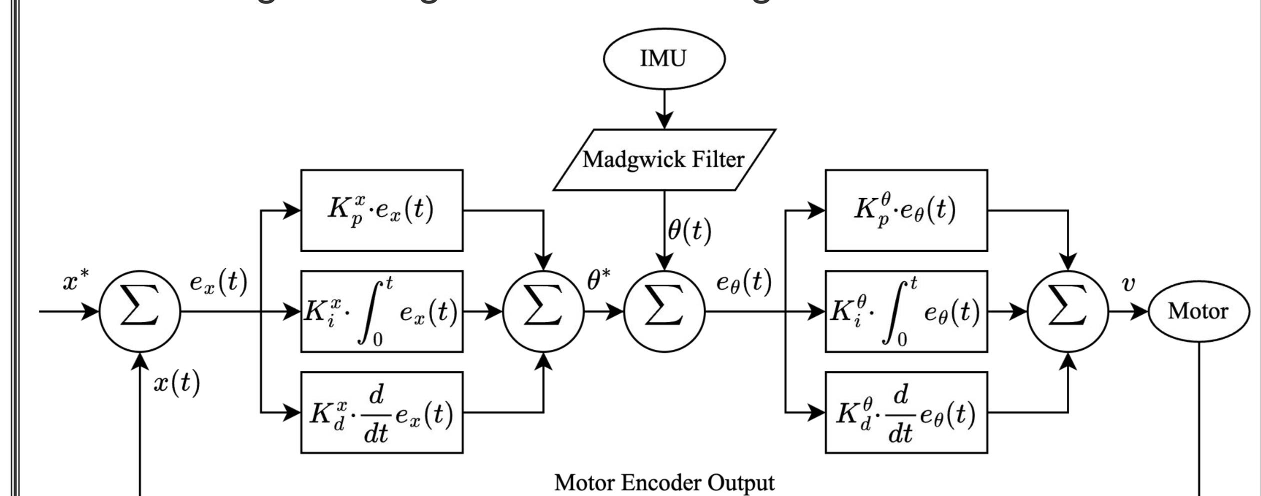

Figure 5. *Cascade PID for Pitch & Position Control*

Testing with the cascade PID controller has revealed that the system is vulnerable to external disturbances and changes in the position setpoint. An alternate solution using a Full State Feedback (FSF) controller is currently being developed. Using LQR for optimizing state and action costs of the system helps with achieving desired performance.

Machine Learning Control

A customizable neural network is being developed as a potential alternative to conventional control, with the goal of better addressing system nonlinearities.

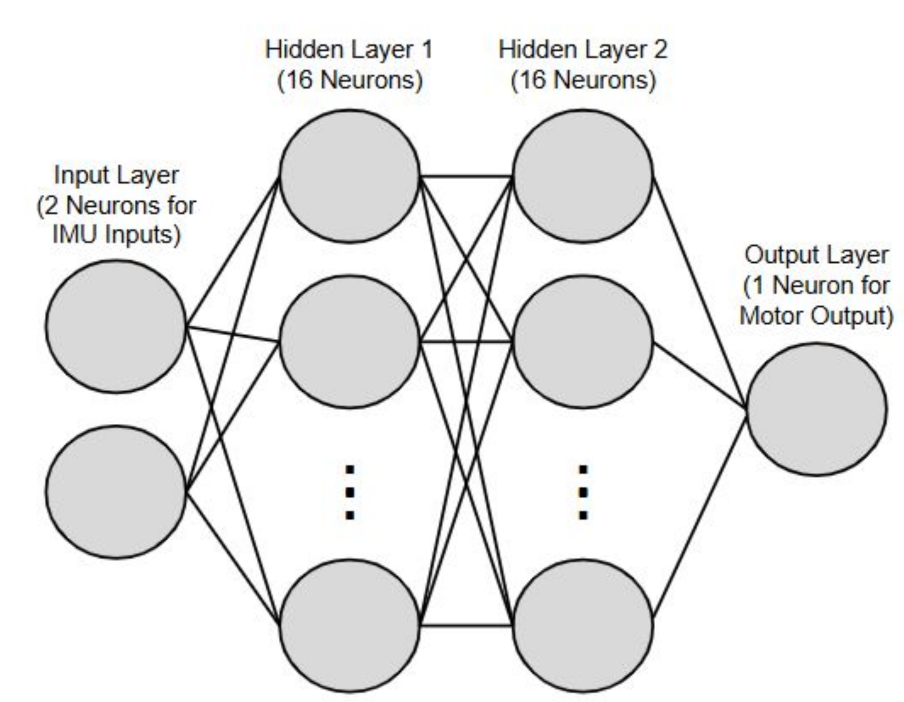

Figure 3. *Neural Network with 2 Hidden Layers & 16 Neurons*

V2 Rover

The V2 rover is designed to assist in laboratory environments by autonomously transporting objects. Inspired by Fraunhofer's evoBOT, it employs a design modeled after a double inverted pendulum, offering high maneuverability, compactness, and adaptability. The main challenge lies in achieving stable control of the system's inherently unstable dynamics under varying loads and shifting centers of mass.

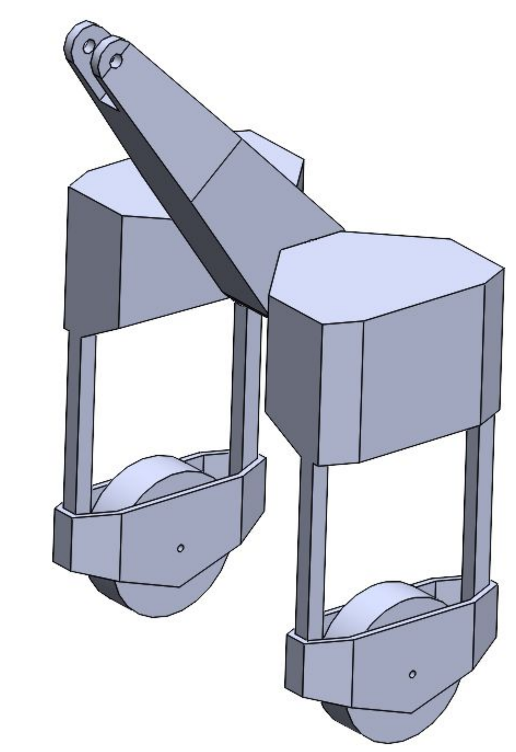

Figure 6. *Conceptual CAD Model for V2 Rover Chassis*

Motor Design

With heavier loads, a custom motor is needed to meet stronger actuation requirements. A BLDC motor with Halbach-array magnets is currently being developed using three-phase electric power, a wye configuration, and an outrunner design. The requirements of this motor are 100 KV, 12–30 volts of operating range, and produces 1 nm torque at 10.5 Amps.

Next Steps

In the upcoming semester, our team aims to further advance and expand our project by finalizing the design and assembly of the V2 Rover. In parallel, we plan to develop and refine both LQR-based and neural network–based controllers for the V1 Rover, enhancing its performance, stability, and autonomy.