

Problem Definition

The BLNC project is developing an inverted-pendulum, self-balancing robotic solution capable of safely transporting sensitive payloads across varied terrain by actively adjusting its center of mass to maintain equilibrium, ensuring stability while adapting to characteristics such as changing inclines and cluttered areas.

Mechanical Design

V1 Rover Design:

The V1 Rover is BLNC's first inverted pendulum robot. It was designed 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.

V1 Design Specifications

Metric	Value
Mass	1.45 kg
Center of Mass Height	20 cm
Max Tilt	$\pm 20^\circ$
Max Torque	1.3 N·m
Battery Voltage	14.8 V
Battery Capacity	1.55 Ah
Material	PETG (Carbon Fiber)

V2 Rover Design:

The V2 Rover is an inverted pendulum capable of interacting with the environment. The rover is designed to pick up payloads by driving over them and deliver them on either side of the chassis to maximize operational usability flexibility.

Payload Specifications

Metric	Value
Max Load	3 kg
Height Range	25-30 cm
Width Range	25-30 cm
Length Range	25-30 cm

V2 Design Specifications

Metric	Value
Mass	13 kg (with max payload)
Center of Mass Height	75 cm
Body Width	70 cm
Arm Length	70 cm
Wheel Diameter	15 cm
Arm Torque	19 N*m, 30 N*m (N=1.5)
Top Speed	3 m/s
Gearbox Reduction	10:1
Sprocket Reduction	10:1
Material	PETG

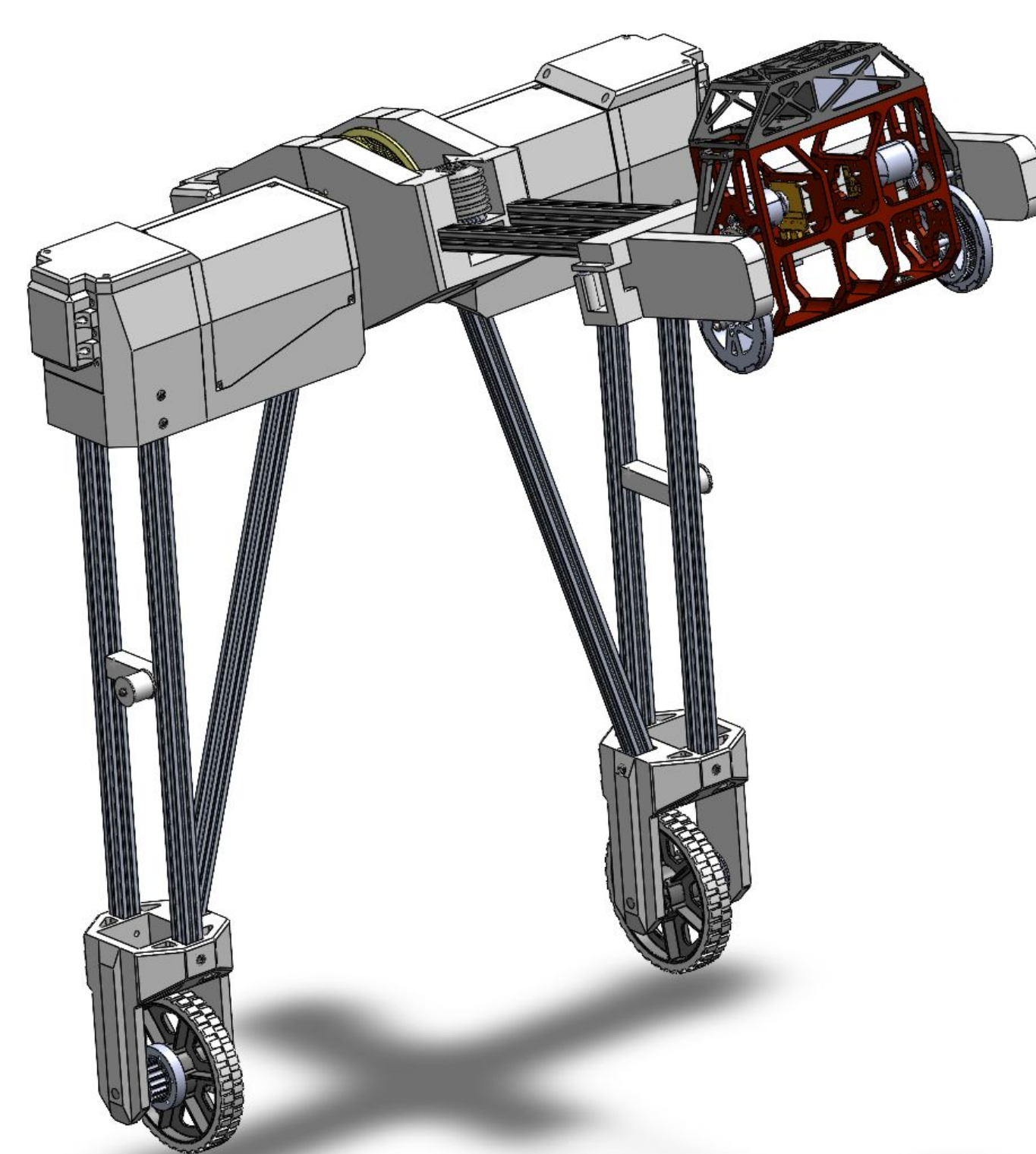


Figure 2. V2 Rover Holding V1 (CAD)

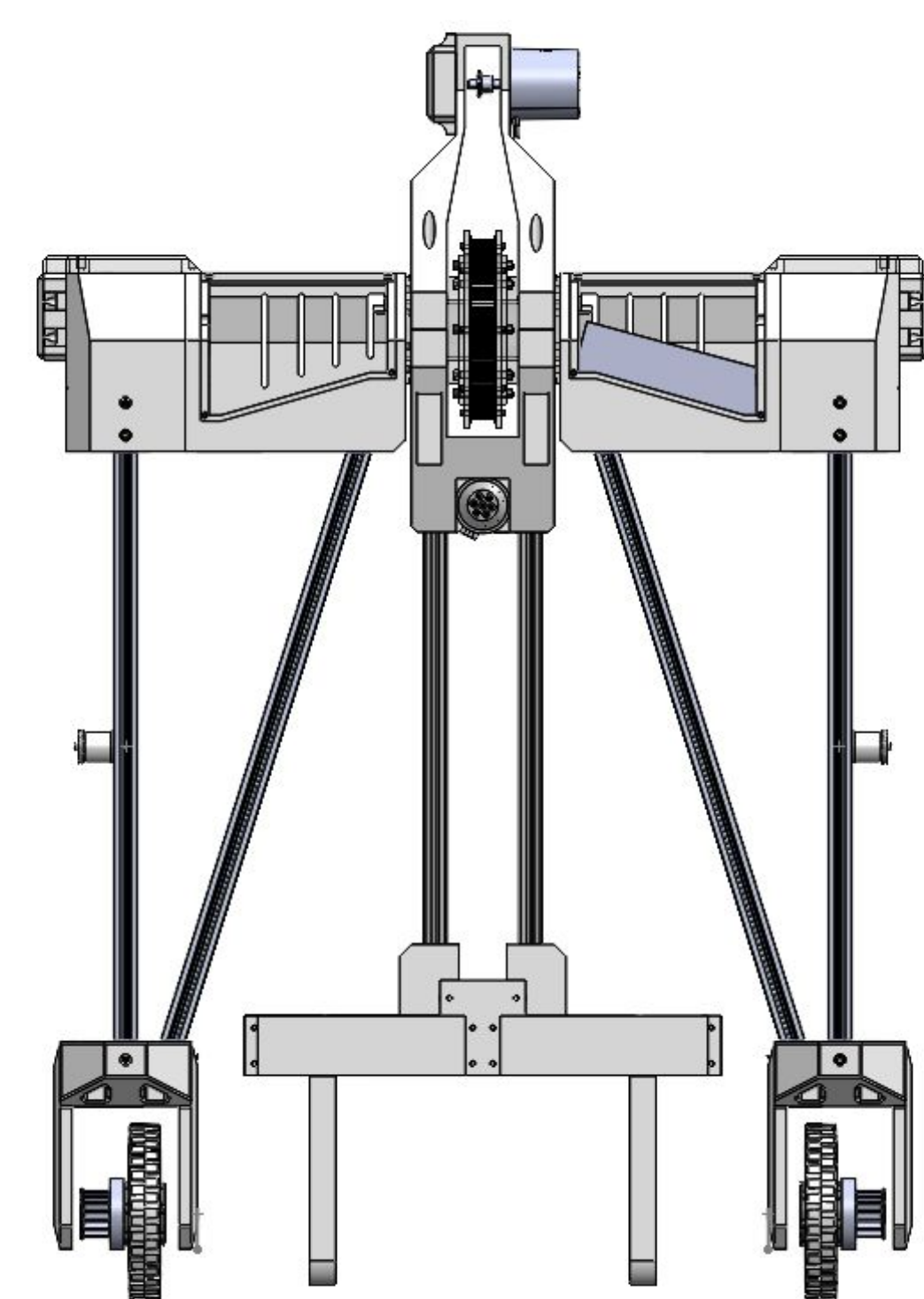


Figure 3. V2 chassis and arm front view

Simulations and Controls

V1 Rover Simulation:

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

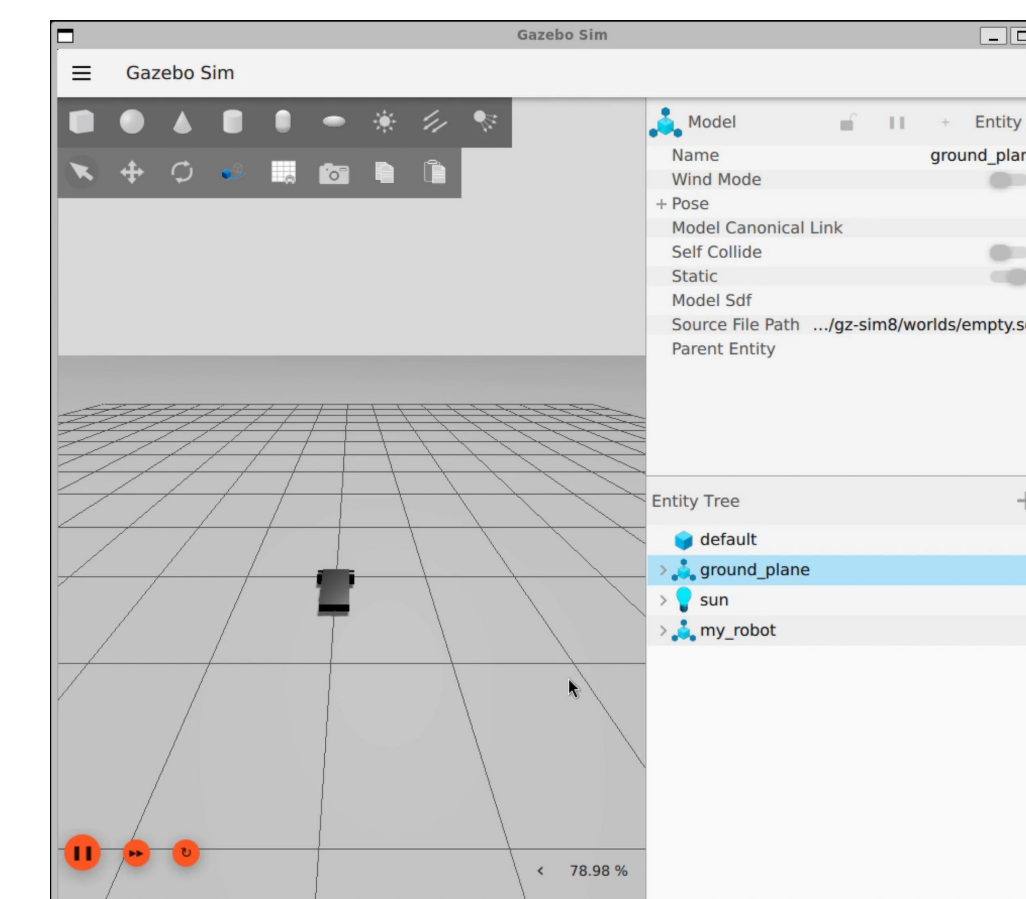


Figure 4. Sample URDF in Gazebo Simulation Environment

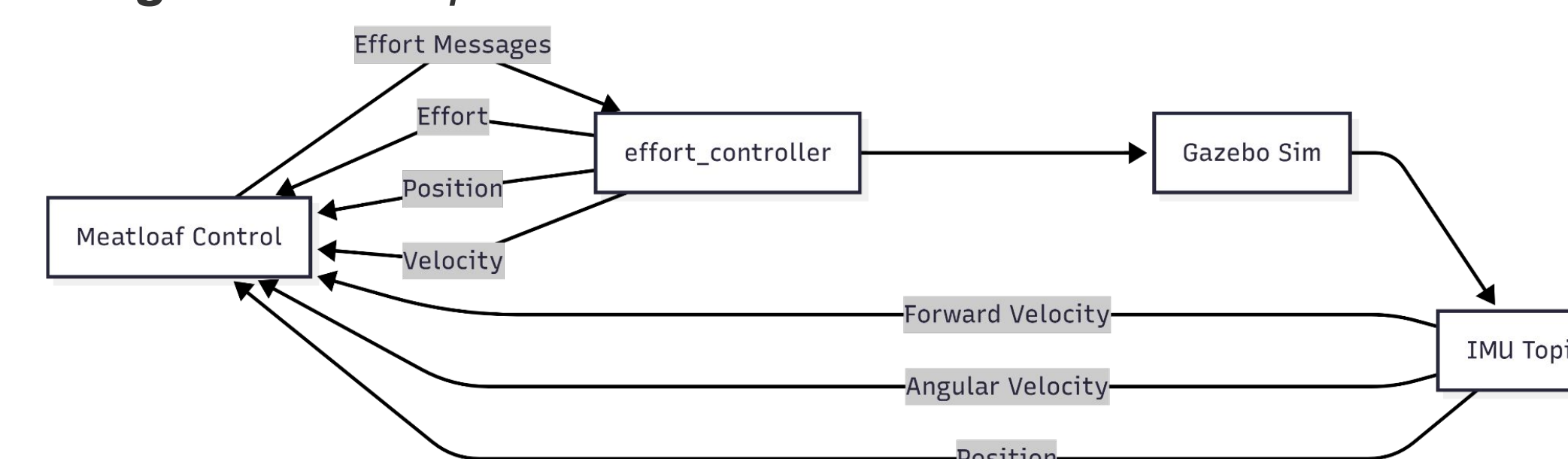


Figure 5. ROS2 Gazebo Workflow

V1 Rover Control:

A cascade 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 via trial and error.

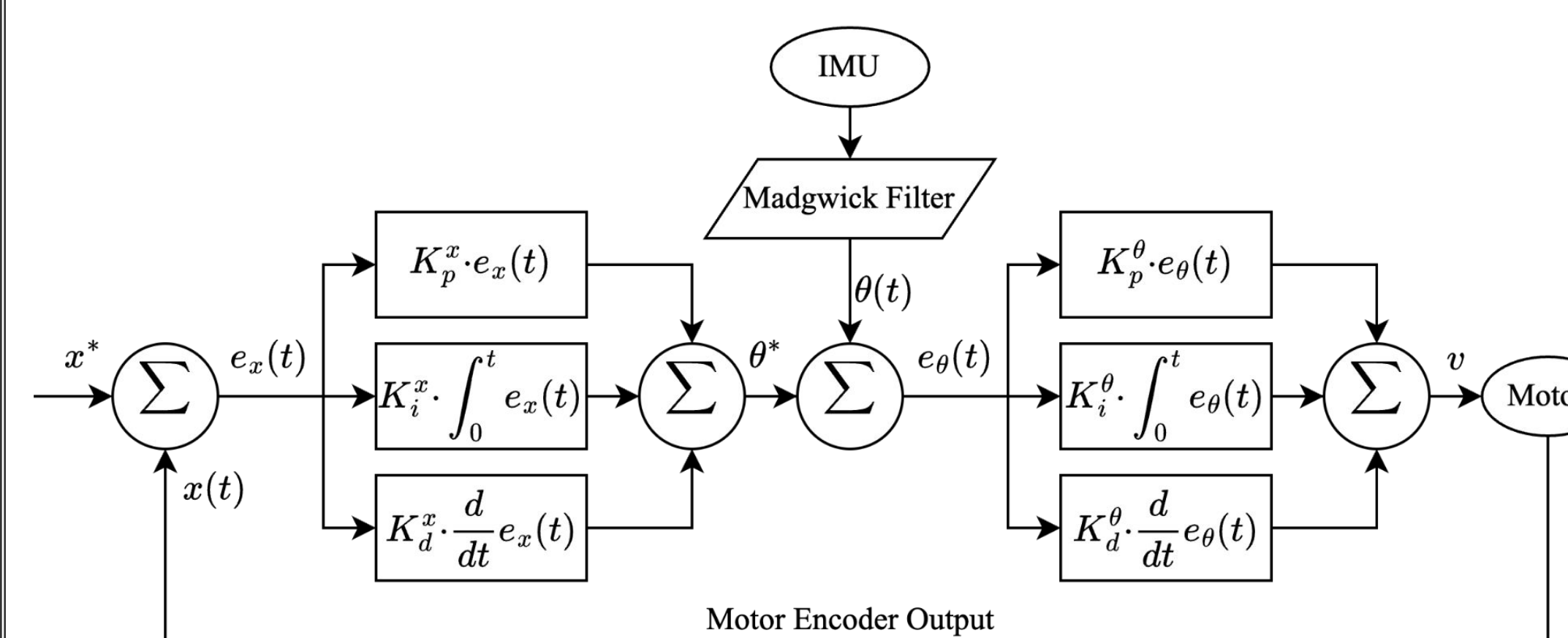


Figure 6. Cascade PID for Pitch & Position Control

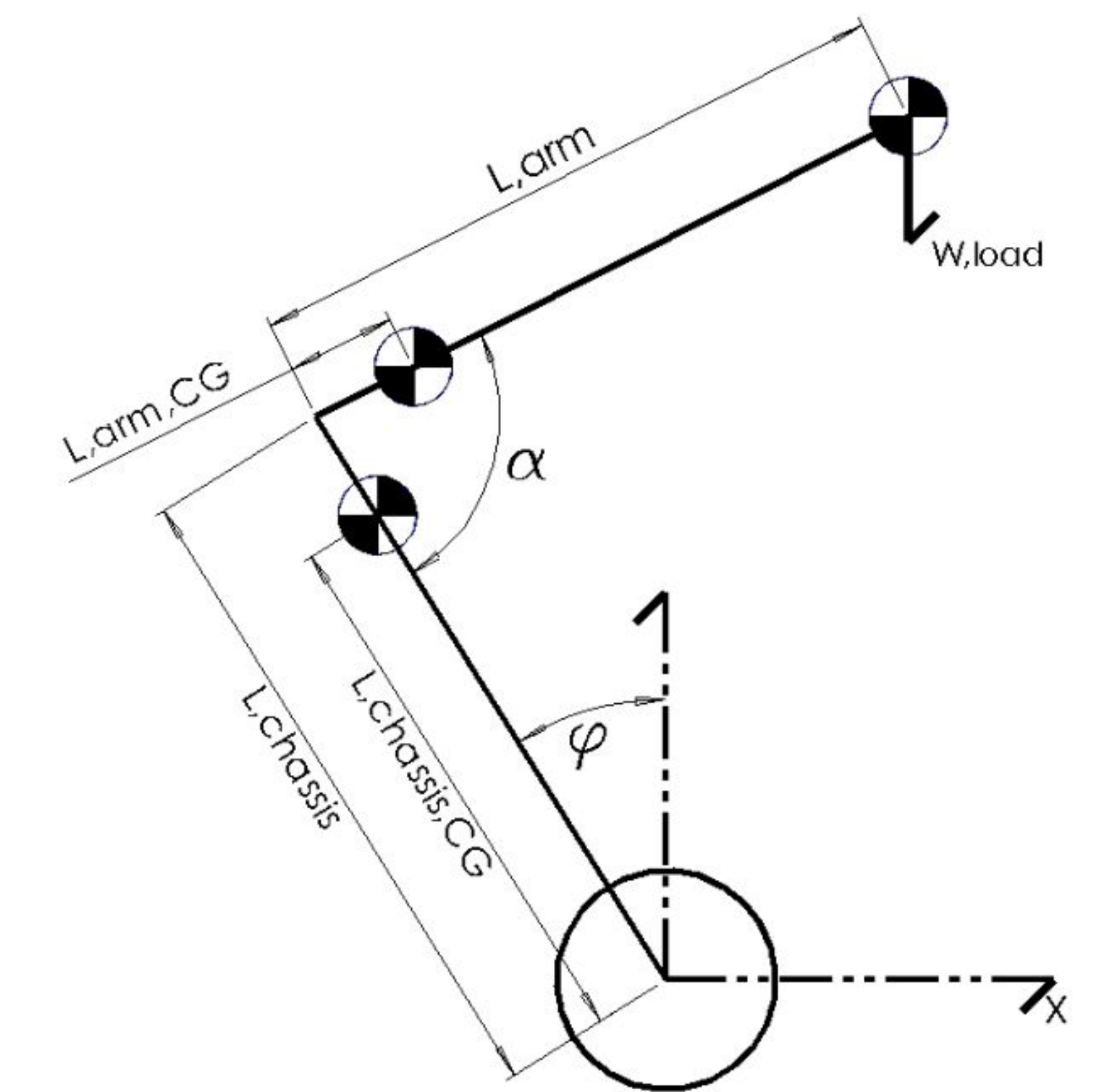


Figure 7. V2 simplified dynamics model

V2 Rover Controls:

From our research, we found that the challenge of control with unknown loads and system nonlinearity is handled using reinforcement learning. We plan to approach it from a traditional control approach so that we have more control over system performance. We currently have developed equations of motion and identified points of non-linearity in the system mode.

$$\frac{d}{dt} \begin{bmatrix} x \\ \dot{x} \\ \varphi \\ \dot{\varphi} \\ \alpha \\ \dot{\alpha} \end{bmatrix} = \mathbf{A} \begin{bmatrix} x \\ \dot{x} \\ \varphi \\ \dot{\varphi} \\ \alpha \\ \dot{\alpha} \end{bmatrix} + \mathbf{B}U_{chassis} + \mathbf{E}U_{arm} \quad (1)$$

$$U_c = (m_w + m_c + m_a) \ddot{x} \quad (2)$$

$$0 = (I_c + I_a) \ddot{\varphi} - (m_c l_{c,CG} + m_a l_c) g \sin(\varphi) - m_a l_a g \sin(\alpha - \varphi) \quad (3)$$

$$U_a = I_a \ddot{\alpha} + m_a l_a g \sin(\alpha - \varphi) \quad (4)$$

Figure 8. V2 rover dynamics and state space

Conclusions

Our work this semester has been primarily to understand the challenges associated with controlling this style of robot. In the coming semester, we plan to assemble the rover and begin controls implementation on the rover once tested and validated in simulations.