TEXAS A&M UNIVERSITY Engineering

TURTLE Quadrupedal Robot (QUAD)

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TEXAS A&M UNIVERSITY
ROBOTICS TEAM & LEADERSHIP EXPERIENCE

Project Statement

Legged robots are more agile and adaptable than robots using other forms of locomotion. The purpose of this project is to design and manufacture a robot capable of balancing and maneuvering on four legs to better understand the capabilities of walking robots.

Approach

Robotic quadrupeds are not a new concept by any means. This project has drawn heavy inspiration from other quadrupedal robots including Boston Dynamics' Spot, MIT's Mini Cheetah, James Bruton's openDog V3, and Ian's initial prototype. To create a working robot, the team started with robot dimensions similar to the Mini Cheetah, known as QUAD V1. Upon realizing the difficulty of testing on a large and expensive robot, a smaller version was created in order to serve as a software testbed. Most recently, V2 was completed taking from the shortcomings from V1 and the framework of mini and improved upon them. The team designed a cycloidal drive used in the leg joints of QUAD V2.

Previous Models

QUAD V1

The first revision of the QUAD was designed to 3 main joints on each leg: an upper and lower leg joint, and a shoulder to enhance maneuverability. The robot uses a tie rod to actuate the lower leg, which allows the actuator to reside in the upper leg and lowers the leg's inertia. Silicone molded feet were chosen to increase grip and prevent slipping on smooth surfaces. The robot is driven by a Raspberry Pi 4 computer and uses an offboard PWM driver to control all leg motors. Additionally, an IMU and LiDAR sensor were added to experiment with mapping and walking on uneven terrains.

Mini QUAD V1

As a scaled version of the QUAD V1, Mini QUAD V1 was created to demonstrate the walking capabilities of QUAD V1 at a smaller and more maintainable scale. The robot has a similar design to the QUAD V1, and serves as a testbed for software development.

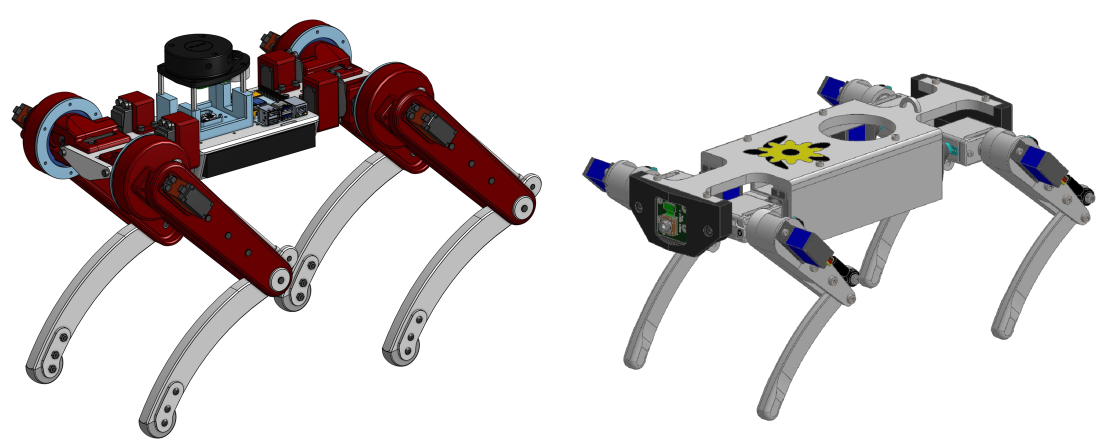

Figure 1. CAD models of QUAD V1 (left) and Mini QUAD V1 (right).

QUAD V2

The second revision of our quadruped model (*figure 2*) implements improvements to several issues seen in the first revision robots. The new design aims to improve the first iteration by maximizing weight capacity, battery life, modularity, and controllability while minimizing cost, with an additional constraint of being entirely 3D printed.

The legs are designed to support a high load including the weight of the chassis and a small external load. The robot is driven by high-torque, 600W mj5208 brushless motors on each of the 12 joints. To amplify the torque output, the team designed a 19:1 cycloidal gearbox to increase the torque output from the motors from 1.7 N·m to 32.3 N·m.

Figure 2. CAD model of QUAD V2.

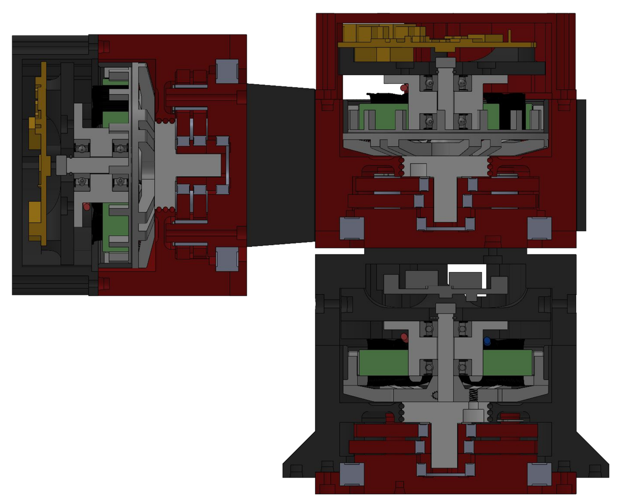

Figure 2. Section View of Cycloidal Actuator CAD model.

The virtue of our cycloidal gearboxes is their backdrivability in a large single-stage gear reduction. This is important in legged robotics to allow the robot to comply and adapt to its environment. The legs also are designed to be modular. The shoulder, upper leg, and lower leg joints consist of the same gearbox, shown in *figure 2*, and similar motor mounting architecture that is easy to disassemble and replace.

The chassis follows the modularity seen in the legs. It is designed in three segments, shown in *figure 3*, with a near-identical front and back modules and a center module with dividers between. The chassis frame is constructed with 1" PVC pipes along the four edges of the chassis, which the modules are slotted on. With repairability in mind, the chassis features removable magnetic panels on each module to access the hardware and electronics within. The center module supports two 12 A·h, 22.2 V lithium polymer batteries for a maximized battery life.

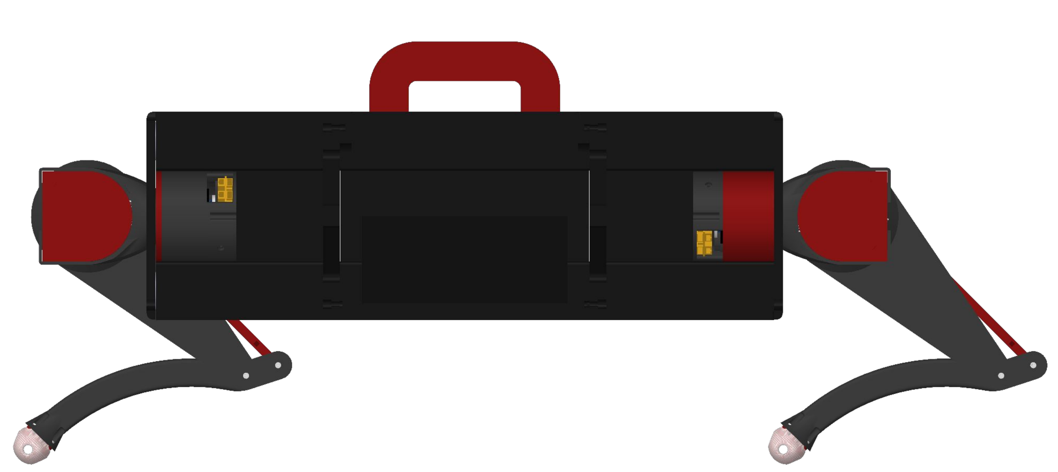

Figure 3. QUAD V2 Chassis Section View.

$$\mathbf{p} = \begin{bmatrix} x & y & z + r_f \end{bmatrix}^T \tag{1}$$

$$\boldsymbol{\theta} = \begin{bmatrix} \operatorname{arctan2}(z, y) - \arccos\left(\frac{l_s}{\sqrt{y^2+z^2}}\right) \\ \operatorname{arctan2}(\sqrt{y^2 + z^2 - l_s^2}, x) - \arccos\left(\frac{l_u^2+x^2+z^2-l_l^2}{2l_u\sqrt{x^2+y^2+z^2-l_s^2}}\right) \\ \arccos\left(\frac{l_s^2+l_u^2+l_l^2-x^2-y^2-z^2}{2l_u l_l}\right) \end{bmatrix} \tag{2}$$

The control system of QUAD V2 implements gait generation fed into to an inverse dynamics model to generate torque setpoints for the joints. The inverse kinematics used in the inverse dynamics model are described in *equations 1 and 2*. The control system is run on a Raspberry Pi 4 with the mjbots Pi3 Hat.

Conclusion

The TURTLE Robotics QUAD V2 is a uniquely inexpensive and capable robot, optimized for strength and modularity. The robot is particularly accessible as a low-cost option. The cost breakdown in *table 1* provides a final cost of $2,400, which is competitive compared with other robots on the market (*table 2*). The 19:1 gearboxes designed for QUAD V2 produce a high torque with low losses and high backdrivability in a compact volume, and are entirely 3D printed. The gearboxes can be used in other low-cost robotics projects requiring high torque and backdrivability. QUAD can now be used as a test platform for legged locomotion and path planning, and can be used in human-designed environments for completing difficult tasks.

Table 1. QUAD V2 Cost Breakdown

Category	Price
Motors	$828
Motor Controllers	$748
Electronics	$553
Hardware	$145
PETG Filament	$127
Total	$2,400

Table 2. Quadrupedal Robot Cost Comparison

Robot Name	Price
TURTLE QUAD V2	$2,400
Unitree Go2	$3,100
MIT Mini Cheetah	$5,900
Boston Dynamics Spot	$74,500
Ghost Robotics Vision 60	$150,000