Woofer and Pupper: Low-Cost Open-Source Quadrupeds for Research and Education

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I. Introduction

There is a lack of general-purpose open-source hardware for legged locomotion research. As a result, many labs spend significant effort developing their own robots, and it is often difficult to reproduce published experimental results.

We have developed two robots: one high-power robot, called Woofer, and one inexpensive and robust robot, called Pupper. Design models and source code for both of these robots are currently available online and detailed documentation will soon be available. These robots are also significantly less expensive than most other research quadrupeds.

II. Background

Quadruped designs have generally converged towards using brushless direct current (BLDC) motors because of their high power density [1] [2] [3]. At the same time, BLDC motors have dropped in price significantly over the past several years due to their large scale production for the drone industry. The motors are typically paired with a low-reduction transmission to meet locomotive torque requirements while also minimizing the inertia of the actuator, which has an inverse relation to the transparency [1].

Another important development that has allowed for the adoption of BLDC motors is the availability of open source motor drivers with field-oriented control that replace the custom motor drivers in previous robots. These motor drivers have been successfully used in Stanford Doggo and Berkeley Jelly [1].

III. Woofer

Woofer is a torque-controllable, 8 kg quadruped robot that features powerful brushless motors in a lightweight frame. This allows the robot to achieve high body accelerations and agile behaviors. Each of the twelve actuators use a 4:1 belt reduction. Although the common approach of a single-stage planetary drive enables higher reductions with similar transparency, the belt drive is lighter than a comparable planetary system and the natural elasticity in the belts protects the transmission from impact loads. The robot also shares a similar kite-shaped parallel linkage to Stanford Doggo to reduce the actuator torque needed to stand compared to a serial linkage. The total cost of manufacturing and components required to build Woofer is about $6,000, which is much cheaper than comparable quadrupeds.

Woofer has a control and estimation stack written in Julia with an EKF-based state estimator and an LQR balance controller. Julia allows easy prototyping while performing similarly to C++ code with some tweaking. Future work will focus on an MPC-based walking algorithm for Woofer.

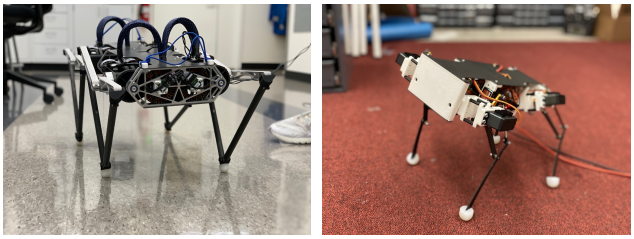

Fig. 1: Woofer (left), Pupper (right)

IV. Pupper

Pupper is a twelve degree-of-freedom quadruped with a similar architecture to Woofer, but uses inexpensive hobby servo motors and 3D printed framing to greatly reduce the cost and build complexity. In total, the manufacturing costs and components total less than $600, making it accessible for students and educators in undergraduate and K-12 institutions. Using servo motors in the robot precludes torque control because of backlash effects and the high reflected inertia, but despite this limitation, open-loop control strategies derived from Raibert-style heuristics allow the robot to achieve hopping and multi-directional trotting [4]. In addition to education, the robot has potential as a reinforcement learning benchmark platform because it is inexpensive, robust, and can achieve dynamic gaits.

References

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