Development of a Hybrid Wheel/Leg Robot Using a Geared Coaxial Shaft Mechanism

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Introduction

Autonomous terrestrial robots have applications in areas ranging from search and rescue, to exploration, to industrial inspection. They can survive environments that humans can't, and can make sustained efforts without resting, unlike humans. However, autonomous terrestrial robot are often limited by their locomotion capabilities, as wheeled robots struggle with rough terrain. Legged locomotion systems, which can better handle obstacles and rough terrain, have issues with power consumption, control complexity, and poor stability. Past research in locomotion systems has combined wheeled and legged locomotion to maximize the performance benefits of each, switching between the two systems when beneficial.

We present development of a mechanism that transforms to combine the benefits of wheeled and legged locomotion, enabling rough terrain navigation while saving on power consumption and maintaining the stability of wheeled locomotion.

Mechanism Overview

Our locomotion system uses a geared coaxial shaft mechanism to shift between two forms of locomotion, wheel, and legged-wheel.

The system is driven by two motors, each on one shaft. When one motor spins faster than the other, the internal geared shaft spins faster than the outer shaft, rotating the legs outwards and changing to legged-wheel mode.

Placeholder (mechanism pic)

To go back to wheel mode, the other motor is spun faster, causing the opposite effect. This mechanism allows for intermediate states between wheel and legged-wheel modes.

Mechanism Design

Initial Prototype

Placeholder (prototype pic)

We developed an initial prototype to demonstrate the mechanism principles. This prototype shifted between the two modes with hand actuation.

Second Prototype

Placeholder (prototype pic)

Our second prototype was of similar design to the first but used motors to actuate the two shafts. It also was able to be fixtured for testing.

Prototype Testing

Placeholder (testing pic)

We have conducted initial testing of our second prototype. By controlling motor speed differential, we shifted between locomotion modes.

Controller Design

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We have developed an initial control system for the mechanism, using two PID control loops. The first controls the velocity of the outer shaft, which controls the speed of the wheel and therefore the robot velocity. The other controls the speed differential of the two shafts by controlling the inner shaft. These two control loops allow us to control the system to reach a desired locomotion mode state and velocity.

Future Controller Development

State Space Control

We will explore modern control methods for this system, including state space control, which will allow for better simultaneous control of all system parameters.

Adaptive Control

We will also apply adaptive control methods to this system. Adaptive control allows a system to adapt to changing dynamics, such as variable rough terrain.

RL-Based Control

We will use reinforcement learning to develop control policies. Through training in simulation, we will create control policies robust to a variety of terrain conditions.

Future Hardware Development

Further Prototyping

We will continue prototyping the mechanism itself, moving towards more robust versions that are able to bear the load of a full robotic system. We will also work towards scaling the mechanism down to enable integration with a system of the desired size.

Leg Design Space Exploration

We will also explore design of the legs. We will explore curvature of the legs, length and thickness of the legs, and quantity of legs. We will explore how different leg configurations perform on different terrains and see whether there is a universally optimal leg configuration, or how tuned leg design needs to be to the desired terrain.

Robotic System Integration

Finally, we will work to integrate the mechanism into a full robotic system. We will mount four copies of the mechanism to a chassis as all four wheels of a differential drive system. We will include sensors such as an IMU, a camera, and distance sensors, a central computer to control the motors and process sensor data, and an onboard power system.

Future Experimentation

Motion Capture

We will run experiments using a motion capture system to precisely track the state of our robot. Using this system, we will be able to determine how accurately our controllers are able to track our desired velocities and locomotion mode states.

Obstacle and Uneven Terrain Navigation

Our experiments will also focus on obstacle and uneven terrain navigation. We will determine how our controller and mechanism perform on different terrains and see how robust they are to novel obstacles. We will generate and 3D print randomized uneven terrain and obstacles of various sizes.