Dynamic Modeling and Control of the Minitaur Platform

Final Project Proposal

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16-868 Biomechanics and Motor Control

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1 Overview

We propose to study the dynamics, controls, and energetics of quadrupedal locomotion in the context of the UPenn / Ghost Robotics Minitaur [1] robotic platform. To this end, we will begin by creating a high fidelity `Simulink` model of the system, including both rigid body and actuator (idealized brushless DC motor) dynamics. Using this model, we will prototype an active compliance control architecture in order to implement a variety of common quadrupedal gaits. Finally, we will study the energetics of locomotion for this system as a function of speed in order to determine an energetically-optimal policy for gait switching. These results will be related to existing findings for quadrupedal animals.

2 Motivation

Among the most important modern robotics challenges is one that enables robots to operate safely in uncertain environments. Better solutions are necessary before robots can operate in homes or other human spaces; interact with objects in complex, underdetermined ways in the presence of uncertainty; or approach anywhere close to the agility and efficiency achieved in human and animal locomotion and manipulation. Building complex interactions with the environment through active compliance and sophisticated controllers may be key to achieving these complex interactions.

Direct-drive robots are necessary for such investigations. In particular, they enable simpler sensing and controls by bypassing nonlinear effects such as backlash that typically occur in geared systems, which further allows active compliance [2]. The Minitaur is a small, quadrupedal, direct-drive robot that moves by walking, trotting, or bounding depending on the terrain and the walking speed. The Minitaur is a rigidly connected system with no elastic element nor gearing between its electric motors, legs, and the ground. The legs can still act like springs, with the effective spring constant determined by a controller. The Manipulation Lab will be acquiring the Minitaur in the next few months. In advance of its arrival, we will study it in simulation to better make use of the physical system. By experimenting with active compliance systems and validating them on a variety of gaits, we can be better prepared to use the physical system in a variety of experiments.

3 Planned Effort

3.1 Expected Timeline

1. **Nov 7:** Develop a dynamic model of the Minitaur in `Simulink`.
   (a) [**4 Days**] Determine pertinent system features to model and simplifications to make. (RMA, AP)
   (b) [**3 Days**] Find and/or estimate system parameters. (TN, AV)
   (c) [**12 Days**] Construct `Simulink` model. (RMA, TN, AP, AV)
   (d) [**3 Days**] Perform basic test cases to validate model against common sense. (AP,TN)
   (e) [**Contingency Plan**] Construct a planar model of the system.
2. **Nov 17:** Investigate and design a locomotion controller.
   (a) [**3 Days**] Research into active compliance control for legged locomotion. (RMA, AV)
   (b) [**7 Days**] Implement an active compliance control architecture. (RMA, TN, AP, AV)

   (c) **[Contingency Plan]** Select 3 spring constants from the literature for the different gaits.

3. **Nov 27:** Model quadrupedal walking, trotting, and bounding gaits.
   (a) **[7 Days]** Develop high-level leg timing controller. (AP, AV)
   (b) **[3 Days]** Implement walking, trotting, and bounding gaits. (RMA, TN)
   (c) **[Contingency Plan]** Remove bounding gait from simulation.
4. **Nov 28:** Investigate system locomotion energetics.
   (a) **[3 Days]** Examine energetics of gaits at various speed to discover transition policy. (RMA, AV)
   (b) **[2 Days]** Compare the simulation's cost of transport to biological quadrupeds. (TN)
   (c) **[2 Days]** Compare the simulation's transition speeds to biological quadrupeds. (AP)

3.2 Stretch Goals

1. **Dec 2:** Examine effects of leg impedance on gait disturbance rejection. (RMA, AP)
2. **Dec 2:** Study effectiveness of various controllers on gait maintenance. (TN, AV)

4 Intellectual Merit

The proposed project would extend our knowledge of walking and running models. The Minitaur is simple enough to model and understand, yet powerful enough to demonstrate sophisticated interaction and controls behaviors. Using this platform, we can develop a deeper understanding of contact modes. We will also understanding why quadrupedal animals alter their gaits at various speeds, and how they are able to recover from disturbances to maintain their current velocity. To our knowledge, the Minitaur has yet to be modeled. By creating a Simulink model, we will be able to better understand the kinematics and controls that the Minitaur uses to navigate different terrain, which can be extended to other robotic quadrupeds.

5 Broader Impact

Deepening our understanding of the Minitaur platform will enable other researchers to more easily build on this work. When a shared platform such as the Minitaur and accompanying tools such as simulations are available, the barrier to entry for new research in robotics is reduced. The systematization of robotics has progressed substantially in recent years, but no direct-drive mobile robot has yet become a standard for researchers. By building additional tools for the Minitaur, we can help in its adoption as a standard research platform, and thus ease the burden of entry for new robotics researchers.

References

[1] G. Robotics. (2016) Ghost minitaur – ghost robotics. [Online]. Available: http://www.ghostrobotics.io/minitaur/

[2] G. Kenneally, A. De, and D. Koditschek, "Design principles for a family of direct-drive legged robots," *IEEE Robotics and Automation Letters*, vol. PP, no. 99, pp. 1–1, 2016.