# Slipping helps steering in a multilegged robot

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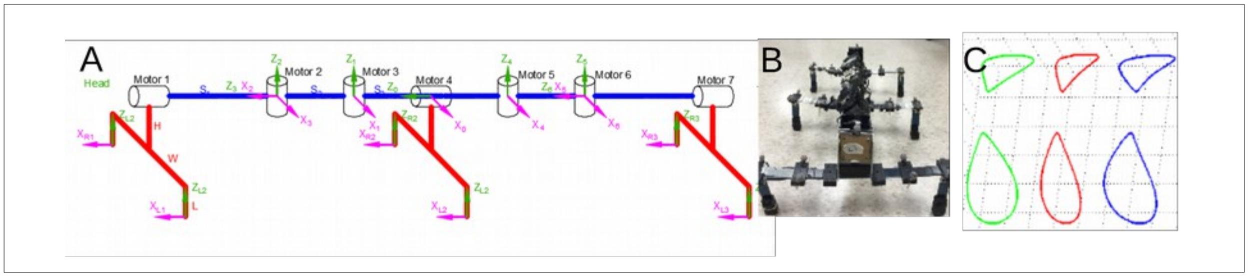

## Summary

Multilegged robots offer a potentially useful locomotion platform for both man-made and uncontrolled environments, as well as functioning as models for the scientific study of biological locomotion. Simple models, computable in faster than real time, are needed for design optimization, model based control, and comparative biomechanics. Commonly, models assume a non-slip contact with the substrate. We present an experimental study of hexapedal "steering": gaits that allow turning while moving forward. Foot slipping is crucial for understanding these gaits in our robot. Surprisingly, increased slipping produces an ***improved*** ability to steer. Turning radii nearly halve and non-dimensional turning rates (deg/cycle) grow by 50% as the distance feet slip is doubled. Yet comparison of the foot motions in the body frame suggests that the geometry of leg motion remains virtually unchanged. We conclude that substantial work is needed to better understand and model multi-legged slipping, and relate body configuration changes to motion in the world frame.

## Introduction

As compared to robots with wheels and treads, legged robots can possess better mobility and maneuverability and lower energy consumption when moving in unstructured environments [1]. Hexapedal robots are particularly appealing due to their ability to remain statically stable at all times, while still moving in the rapid "alternating tripod" gait used by walking and running insects. Rapidly moving insects exhibit Lateral Leg Spring (LLS) dynamics [2], which we have shown to appear in our robots [3].

We examine "steering" - the ability of the robot to change heading and orientation continuously while moving forward. Previous work on steering has focused on either fully actuated (3DOF or more) legs [4], or highly under-actuated robot bodies (1DOF [5], 1DOF [6], 2DOF [7]). We focus on a unique design which allows alternating tripod gaits to be generated with what are effectively 2DOF per leg with only 7 motors in the entire robot (Fig. 1A, B).

## Methods

Our robots are based on the design of Sastra, et.al. [8]. These hexapods allow for dynamic gaits – as indicated by running gaits with fully aerial phases – despite being constructed from highly geared down hobbyist servos (Dynamixel RX64 and EX106; Robotis Inc) driving compliant legs. The compliance comes from a steel spring (1095 Spring Steel) at the base of each leg.

Using a rigid-body kinematic model of our robot (Fig. 1A) we modeled the foot trajectories being commanded, with respect to a body frame (Fig. 1C) showing each foot is effectively 2DOF.

To steer our robot, we twisted the backbone (Fig. 1B) adding a constant offset to all leg motors, making them left-right asymmetric.

We ran our robot on a low friction rigid surface (linoleum floor) and a high friction compliant surface (C9 interlocking fitness mat; Target Inc), while collecting motion tracking data at 100Hz using a reflective marker based motion tracking system (6 Oqus cameras; by Qualisys). We used the markers associated with the distal (and rigid) part of each leg to estimate the foot positions. We used markers on the backbone modules to compute the body frame.

## Results

We recorded 3 trials each on each surface, at 20º backbone twist, and 1.3Hz gait frequency. These parameters were chosen based on previous work seeking optimal turning rates.

| | Low friction | High friction |
|---|---|---|
| Radius[cm] | 78,70,68 | 130,126,121 |
| Rate [º/cyc] | 14,15,15 | 10,9,10 |
| Slip [mm] | 70,71,74 | 41,39,42 |

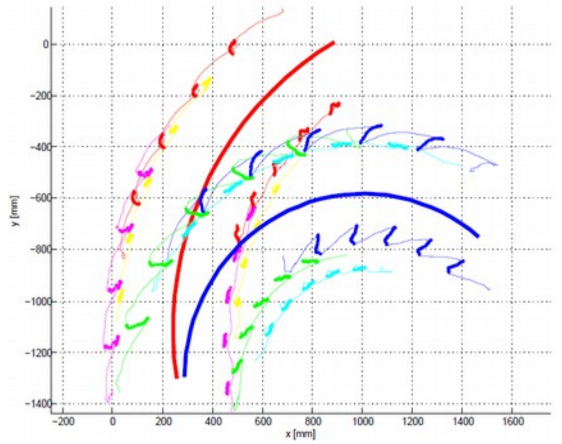

*Figure 2 Steering on low friction (cold colors) and high friction (warm colors). Foot motions shown with slipping highlighted (thicker lines). We used least squares to fit circular arcs (thick red, blue) to find turn radii: 121cm in low friction and 70cm in high friction.*

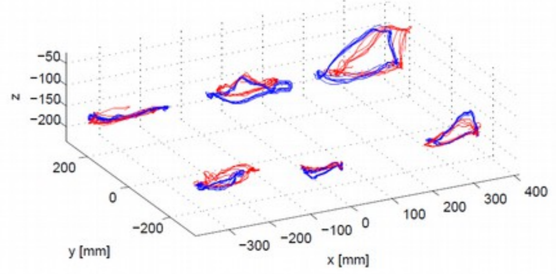

*Figure 1 Foot trajectories in body frame on low (blue) and high (red) friction surfaces. Note that these hardly change despite the large change in performance*

## Discussion

The large change in performance metrics in favor of increased slipping is in direct contradiction to the influence of slipping on wheel and tread based vehicles. The change is made even more intriguing because it seems unrelated to the geometry of foot motions – it is not a consequence of a kinematic change associated with a change in contact forces. We conclude that better understanding of slipping is essential for realistic modeling of multilegged locomotion. [Work funded by ARO grant W911NF-14-1-0573 to Revzen]

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