Some Insights about Multi-legged Steering

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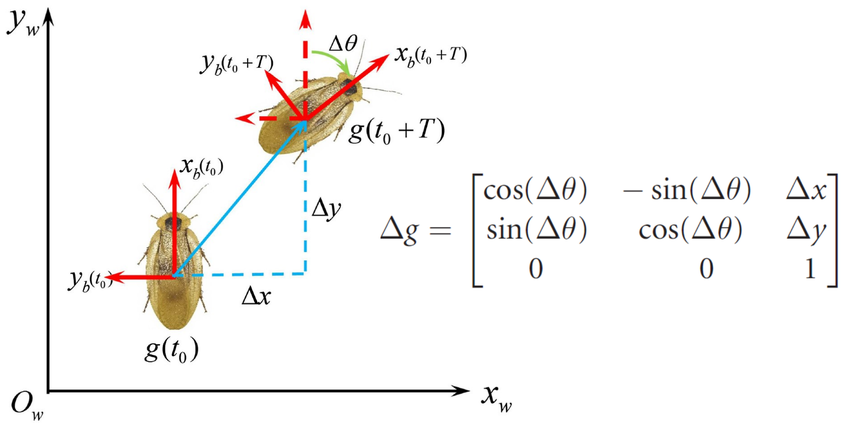
Introduction

A key engineering challenge with hexapods has been to produce insect-like agility and maneuverability, of which steering is an essential part. However, the mechanisms of multi-legged steering are not always clear, especially for robots with underactuated legs. Here we introduce some insights regarding multi-legged steering with low-DoF legs from our research.

What is a steering gait?

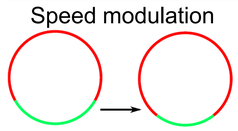
Legged systems typically move using a periodic gait: a cyclic shape-change ***b(t)*** which produces a motion ***g(t)*** through the world, $g(t) \in G = \mathrm{SE}(2)$ for horizontal motion. The holonomy $\Delta g := g(t+T)g^{-1}(t)$ of gait ***b(t)*** is shown in following figure:



$$\Delta g = \begin{bmatrix} \cos(\Delta\theta) & -\sin(\Delta\theta) & \Delta x \\ \sin(\Delta\theta) & \cos(\Delta\theta) & \Delta y \\ 0 & 0 & 1 \end{bmatrix}$$

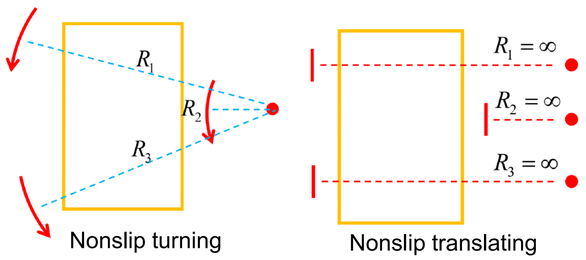
We define steering to be the ability to select the rotational component $\Delta\theta$ of the holonomy Δg within an interval around 0 by employing a one-parameter family of periodic gaits. Thus, a steering gait is a function $b(\phi, s) : \mathrm{S}^1 \times [-\theta_m, \theta_m] \to B$ mapping the phase and steering input to shape space, such that the holonomy $\Delta g(s)$ for the gait $b(\bullet, s)$ satisfies $\Delta\theta = s$.

Steering with low-DoF legs is not trivial



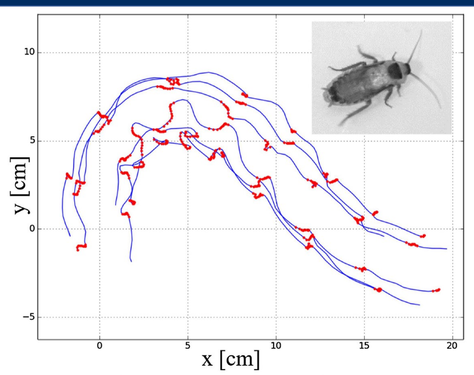
Leg with 1- or 2-DoF can only occupy a 1- or 2-dimensional manifold with respect to the body frame. With such fixed geometry, leg trajectory can only change its speed distribution for steering.

Multi-legged steering with 1-DoF legs has to slip



Robots with multiple 1-DoF legs contacting with ground cannot change their turning radius if nonslip constraint is enforced.

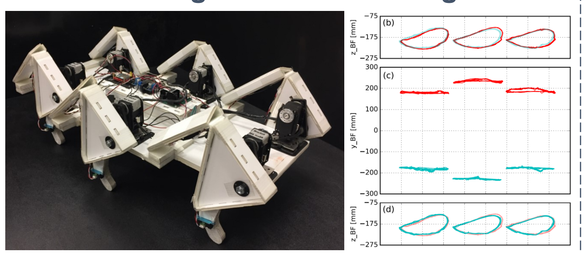
Multi-legged slipping is common in nature



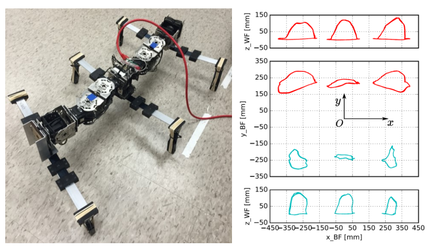
Cockroach (*B. discoidalis*) legs slip 16% of the distance traveled in the lab frame [1].

Steering results for low-DoF hexapods

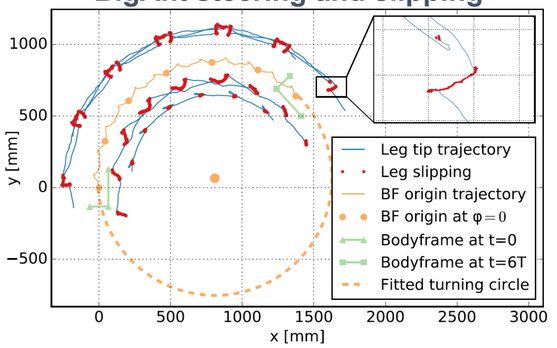
BigAnt with 1-DoF legs



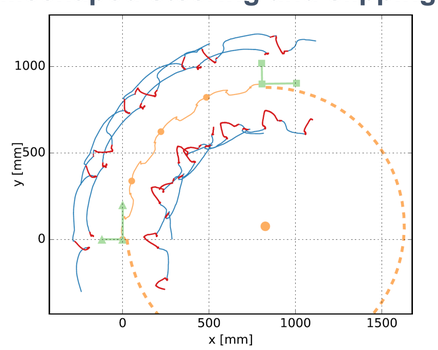
Mechapod with 2-DoF legs

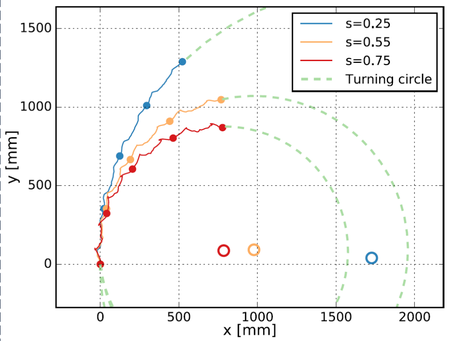


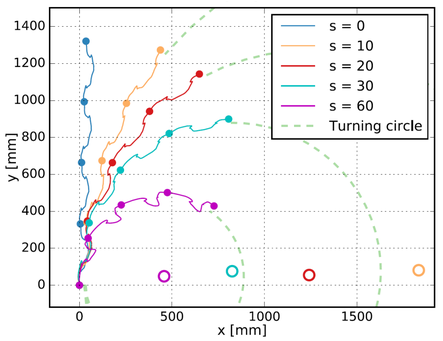
BigAnt steering and slipping



Mechapod steering and slipping







The results show a clear parametric dependence of turning radius on steering parameter value, suggesting both robot platforms achieved steering gaits with low-DoF legs. Also, robot feet slipped a great deal. For Mechapod, a non-slip steering gait is possible, but the turning radius is much larger.

See more details in our publication:

[1]. Zhao, Dan, and Shai Revzen. "Multi-legged steering and slipping with low DoF hexapod robots." Bioinspiration & Biomimetics (2020). Doi: 10.1088/1748-3190/ab84c0