Some Insights about Multi-legged Steering

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I. Introduction

Thanks to their sprawled posture and multi-legged support, stability is not as hard to achieve for hexapedal robots as it is for bipeds and quadrupeds. 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 discuss about some insights regarding multi-legged steering. We propose a formal definition of a "periodic steering gait", and analyze the geometry of steering strategies. We show that for many multi-legged robots, steering is impossible without slipping, and that unique problems arise with low DoF legs. We also present some experimental results from robot platforms using periodic steering gaits.

II. Highlights

A. Definition of periodic steering gaits

Legged systems (animals and robots both) typically move using a *periodic gait*: a cyclic shape-change which produces (at least on average) a motion through the world. The shape-change can be represented by the leg motions in the body frame of the system. The framework of geometric mechanics provides a precise language for describing how holonomies arise from periodic shape changes [1], [2]. The instantaneous configuration $q = (g, b)$ for a robot system is an element in the overall configuration space $Q = G \times B$. The shape space B is typically a compact manifold in R^k for some $k > 1$, and represents the possible shapes of the body, with the current shape being $b \in B$. The instantaneous body frame $g \in G$ is an element of the group G, which for horizonal motions is the group of rigid body motions in the plane, $\mathsf{SE}(2)$. Consider a system moving using a periodic gait with period T, and configuration given by $(b(t), g(t)) \in B \times G$. The body shape $b(t)$ must also be periodic with period T. The holonomy of this gait would be $\Delta g := g(t+T)(g(t))^{-1}$, and is the same for all choices of t. To capture the fact that the gait is defined by a *periodic* $b(t)$ we will take the domain of $b(\cdot)$ to be the unit circle $\mathsf{S}^1 \subset \mathbb{C}$. Instead of thinking of $b(\cdot)$ as a function of t, we shall take $b(\phi)$, $\phi \in \mathsf{S}^1$, and $\phi(t) = \exp(i2\pi t/T)$. 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 $b(\phi, s) : \mathsf{S}^1 \times [-\theta_m, \theta_m] \to B$, such that the holonomy $\Delta g(s)$ for the gait $b(\cdot, s)$ has a rotational part $\Delta\theta$ equal to s. We further require that the map $\Delta g(s)$ be continuous in s, i.e. small changes in steering parameter lead to small changes in the resulting holonomy.

B. Experiment results

We conducted steering experiments on our robot platform: BigAnt [3] which is a hexapedal robot with 1-DoF per leg. Several periodic steering gaits were tested with a variety of steering parameters and speeds. One trial of experiment recorded from Qualisys motion capation system is shown in Fig. 1.

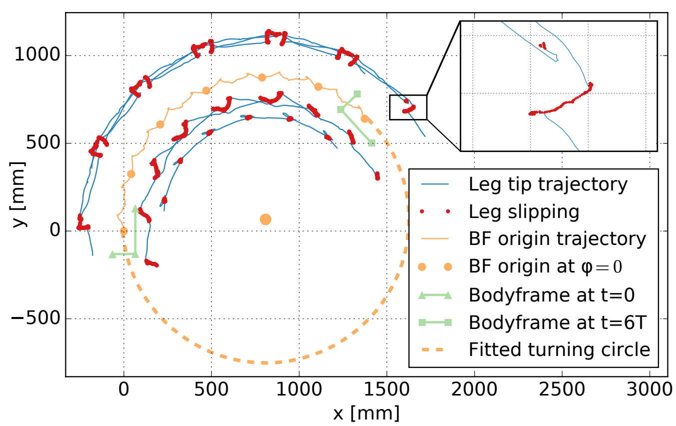

Fig. 1. BigAnt motion in world frame (gait frequency $f = 0.22$ Hz; steering input $s = 0.75$). In this trial, BigAnt turns $23°$/cycle and the turning radius is 818mm. Note: BF stands for Body Frame.

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References

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