Control Strategies for a Rimless Wheel Micro-Rover

Dennis Schlee[1,2]
[1] TU Darmstadt, [2] Robotics Innovation Center (RIC), DFKI GmbH

System Overview

Wheeled robots are widely used for autonomous exploration of unknown environments. A limiting factor of such rovers is that they cannot overcome obstacles higher than their wheel hub. While legged robots have the capability of navigating in more challenging environments, they come with the disadvantage of having higher energy demands. Rimless wheeled robots are a hybrid variant of traditionally wheeled and legged robots. These hybrid systems combine the benefits of both approaches, such as efficient power demands and good terrain traversability.

System Usage

The German Research Center for Artificial Intelligence GmbH (DFKI) - Robotics Innovation Center (RIC) has a long history of developing rimless wheel rovers, including the Asguard series [1] and the Coyote series [2]. These rovers share the properties of being small, lightweight, and having four five-spoked rimless wheels. The robots are highly mobile and are designed to act as scouting platforms paired up with a primary rover for autonomous long term exploration.

Figure: Payload exchange between SherpaTT and Coyote III in the context of the TransTerrA multi-robot system [3].

Vertical Motion

With respect to wheeled systems, the main disadvantage of rimless wheeled systems lies in the impacts caused on the body when navigating rigid surfaces without a gait that pursues the minimization of the forces in these impact phases. The effects of locomotion patterns on the system's vertical motion have been analyzed for the robot Asguard I in [4]. While the paper's locomotion pattern is controlled by setting the motion offsets between the wheels, the authors considered only a limited amount of gaits.

Rimless Wheel Parameter

A standalone rimless wheel is described by the following parameters:

- gravity vector g
- slope inclination γ
- point mass m at the hip
- spoke length l
- angle between two spokes 2α
- orientation of the stance spoke $\theta \in [\gamma - \alpha, \gamma + \alpha]$

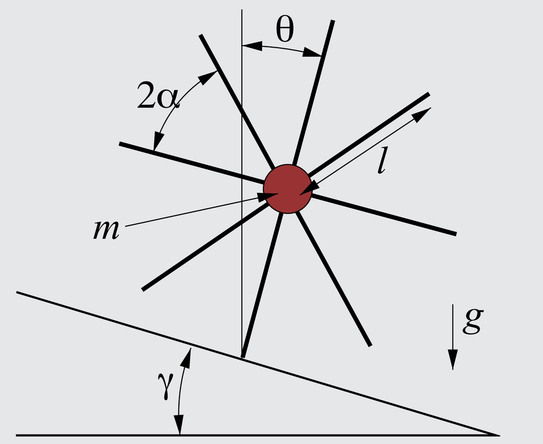


Figure: Rimless wheel parameters [5].

Passive Dynamics

In order to develop sophisticated foot placement control strategies for a rimless wheel rover, the systems passive dynamics have to be analyzed and exploited. For that, the systems phase portrait has to be examined, which is a geometric representation of the orbits of a dynamical system in the phase plane. The plot depicts the phase portrait of a single five-spoked rimless wheel, while it passively rolls down a slope of 20 deg inclination. The phase portrait shows that shortly after initialization, the rimless wheel falls into a stable limit cycle.

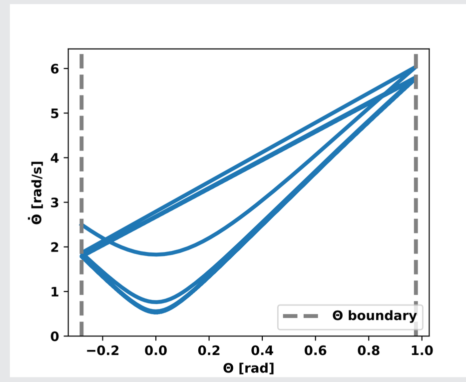
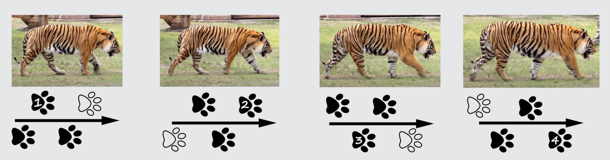
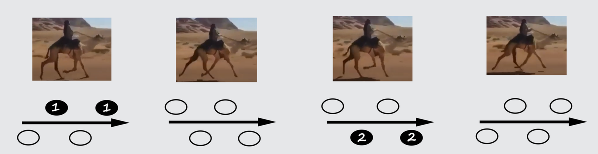


Figure: Passive phase portrait trajectory of the a five-spoked wheel.

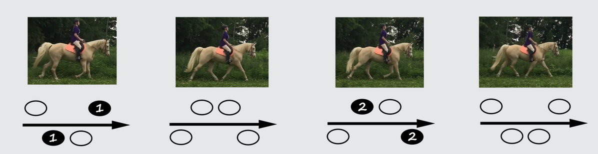
Gait Overview



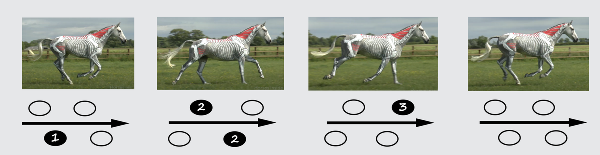
(a) Walk: RL → FL → RR → FR.



(b) Pace: RL & FL → RR & FR.



(c) Trot: RR & FL → RL & FR.



(d) Canter: RR → RL & FR → FL → Suspension.

Figure: Footfall order of different gaits [6].

Gait is the pattern of movement of the limbs of animals during locomotion. The figure above depict the footfall order of selected gaits of different animals with the following notation: Front left (FL), front right (FR), rear left (RL), rear right (RR). These animals can use a variety of gaits, based on speed, maneuverability and energy efficiency.

Simulation

A simple simulation was set up to analyze the effect of different gaits on the vertical motion of the rover center body, the roll-pitch-yaw angles, and the phase portrait of the z-axis. To achieve that, a simplified version of the robot Asguard v4 was modeled using only primitive shapes. The center body consists of a cuboid, and the wheels were substituted for legs made out of elongated capsules. Each leg acts as a prismatic joint, moving vertically the same amount as the Asguard v4 wheel hub when it moves from the single contact to the double contact stance. The footfall order can be produced by phase shifting the vertical motion of the legs.

Gaits used	Footfall order
Hop	all at once
FB-offset	FL & FR → RL & RR
LR-offset	FL & RL → FR & RR
LR-cross-offset	FL & RR → FR & RL
Walk	RL → FL → RR → FR
Roll	RL → FL → FR → RR

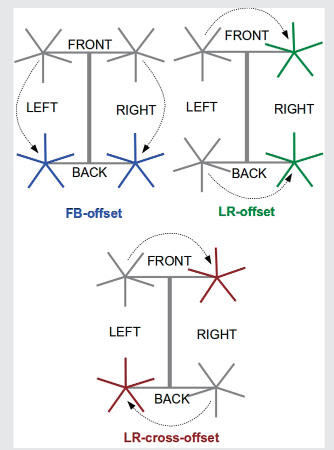


Figure: Wheel offset [4].

Simulation Results

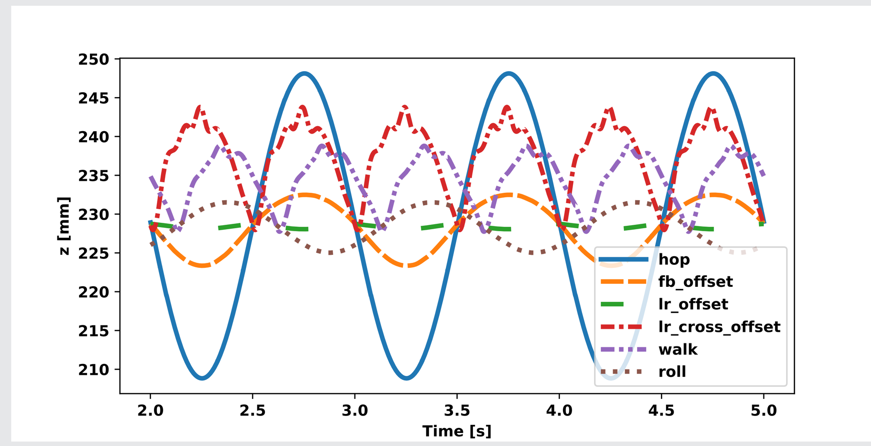
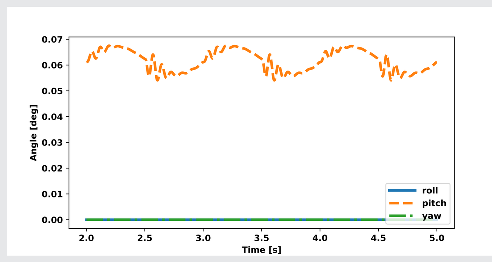
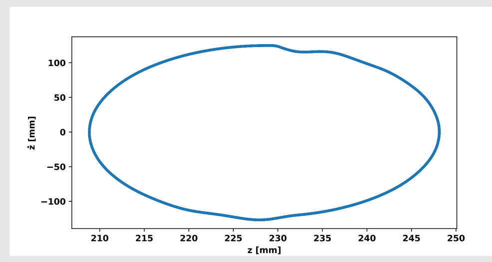


Figure: Vertical motion comparison of all simulated gaits.

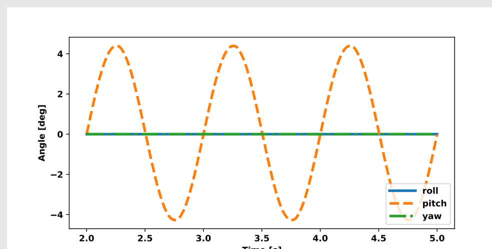


(a) Roll-pitch-yaw angles.



(b) Phase portrait.

Figure: Gait: Hop



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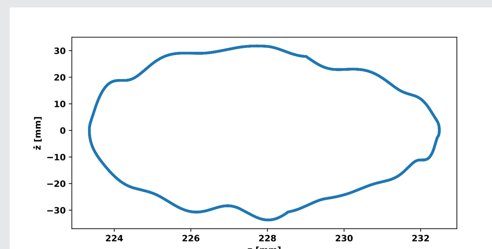
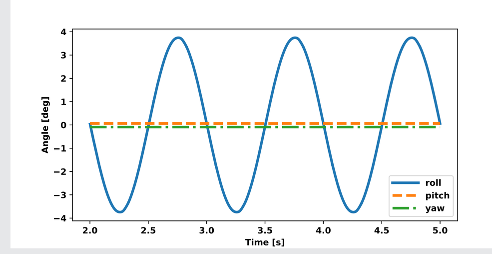


(b) Phase portrait.

Figure: Gait: FB-offset

Simulation Results (cont.)



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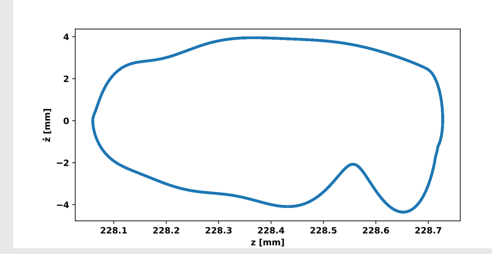
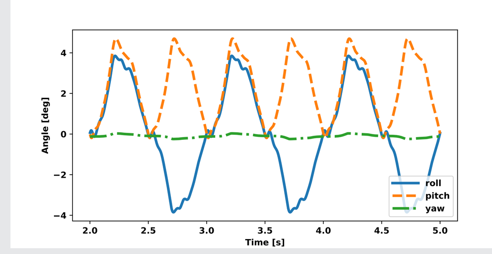


(b) Phase portrait.

Figure: Gait: LR-offset



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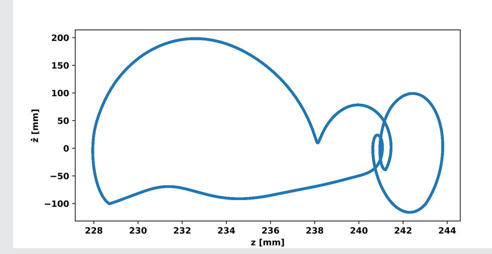
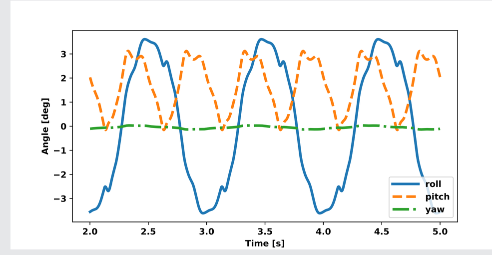


(b) Phase portrait.

Figure: Gait: LR-cross-offset



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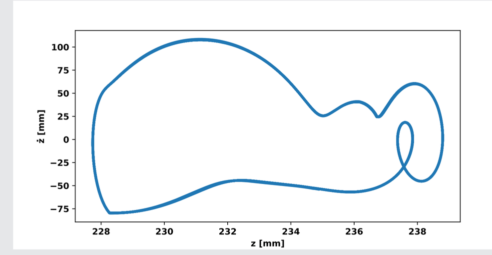
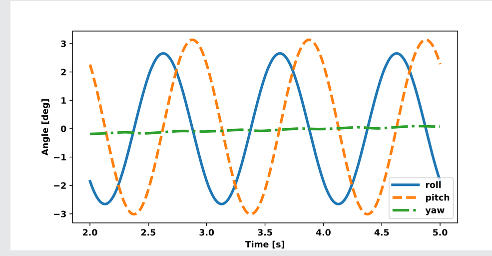


(b) Phase portrait.

Figure: Gait: Walk



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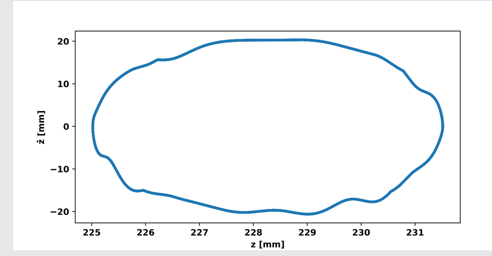

(b) Phase portrait.

Figure: Gait: Roll

Acknowledgment

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References

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[6] *A GUIDE TO QUADRUPEDS' GAITS - Walk, amble, trot, pace, canter, gallop.* Accessed: 2023-09-23.