Kinematic Calibration and Sensor Fusion for Legged Robots

Michael Bloesch, Marco Hutter, Péter Fankhauser, and Roland Siegwart
Autonomous Systems Lab, ETH Zürich, Tannenstrasse 3, 8092 Zurich, Switzerland
bloeschm@ethz.ch

1 Motivation

While the current progress in actuation schemes, sensor setups, and mechanical design allows the development of increasingly performing legged robots, motion planing and control of such systems still pose challenging problems. Our group contributes to the ongoing research by focusing on the calibration, state estimation, and perception of legged platforms. Especially in rough and unstructured terrain, these tasks can be very demanding and are prerequisites for achieving robust and versatile locomotion for legged robots. The developed methods should, ideally, handle difficult environments, arbitrary footfall patterns, or flight phases (see Fig. 1).

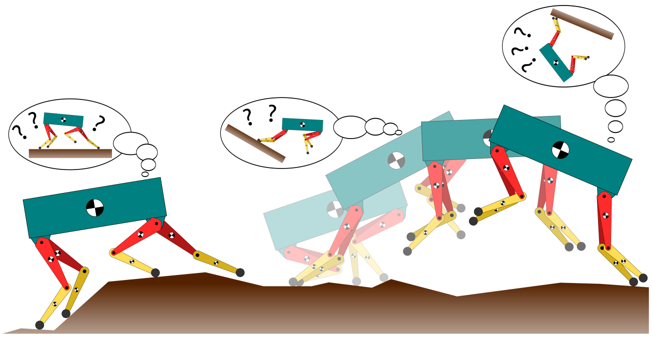

Figure 1: Challenges of Legged State Estimation.

2 State of the Art

Calibration, state estimation, and perception are tasks that depend on each other and exhibit similar issues (e.g. measurement noise, outlier handling, observability issues, high computational costs), whereby the corresponding tools can be shared and combined. The related literature is very vast.

For kinematic calibration, much work has been presented in the context of hand-eye, head-eye or IMU-camera calibration problems. Kinematic calibration approaches can be distinguished into online and batch methods. *Online* approaches filter and refine the estimated parameters at runtime. They can calibrate extrinsic IMU-camera setups including IMU biases [9] and even while being embedded in a simultaneous localization and mapping (SLAM) framework [7]. *Batch* approaches solve a full nonlinear optimization problem in order to find the set of calibration parameters which best explains the measurements of a prerecorded dataset. While the computational expenses are significantly higher, they often yield more accurate results. Some of the interesting results include time continuous calibration framework [5] or the manifold based kinematic calibration [1].

Matching the leg configurations between subsequent timesteps is a common approach for implementing legged odometry [4, 6, 8]. The drawback is, that it requires a minimum of three simultaneous ground contacts and that it is prone to full pose drift. Lin et al. [8] improved this approach by augmenting it with measurements from a mounted IMU in order to handle flight phases on a hexapod robot. Extending the sensor setup on the legged platform with perception like camera or laser ranger setups has been investigated as well. Chilian et al. [4] implemented a multisensor fusion algorithm merging inertial measurements, legged odometry, and visual odometry. In order to avoid position drift, legged odometry has also been fused with GPS data [6].

3 Own Approach

A special aspect of legged robots is that they interact with their surrounding through intermittent ground contacts. While this is exploited for the robots locomotion, it also represents a valuable source of information. Our group studies different methods in order to make proper use of this information and to combine it with further sensor modalities like stereo camera or laser ranger. Therewith we attempt to design state estimation and mapping algorithms which provide the robot with an accurate and fast feedback as well as with a suitable representation of its surroundings. This should enable the design of elaborate planning and control algorithms on autonomous legged platforms.

In order to reach this goal, we combine batch optimization and online filtering techniques and employ stochastic models which accurately capture the sensors characteristics, like foot slippage or measurement bias. We design optimization and filter algorithms which properly handle the intermittent ground contacts and take special care of the fact that rotations are members of the special orthogonal group $SO(3)$.

4 Current Results

In [3] we presented a state estimation approach for legged robots which combines the information from contact kinematics together with IMU measurements. This is implemented on our legged robot StarlETH and enables dynamic locomotion on uneven terrain. It avoids unnecessary assumptions on the shape of the floor or on the employed gait pattern and is robust to a certain amount of foot slippage. In [2] we propose a batch optimization algorithm which calibrates the leg kinematics as well as the inter-sensor coordinate transformations of a legged platform. Slightly altered versions of the optimization process can be combined with the online state estimation in order to improve the estimates' accuracy and to integrate additional sensor modalities.

5 Best Possible Outcome

The goal of our research is to design methods which, together with an appropriate sensor setup, provide a legged robot's planning and control processes with accurate and fast estimates of the state of the robot together with an appropriate representation of the surrounding terrain. In particular, we want to avoid "lab space" assumptions, and want to develop algorithms which can handle unknown terrain, arbitrary locomotion gaits, as well as disturbances like foot slippage or sensor failures.

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