State Estimation in Contact: Application for Legged Robots

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Overview

In this study, we demonstrate an Extended Kalman filter (EKF) state estimator successfully tracking states of the Minitaur quadruped through dynamic behaviors. Our state estimator does not depend on contact sensors for state estimation. We intelligently fuse the foot position and foot force estimate from momentum observer to estimate the probability of contact. We use the IMU as the process model, and leg kinematics from established contacts as the measurement update in this Kalman filter framework.

Motivation

- Increasing number of applications for autonomous legged robots in unstructured terrains
- Accurate robot state representation required for feedback control and motion planning
- Contact state needs to be estimated proprioceptively due to reliability issues of contact sensors

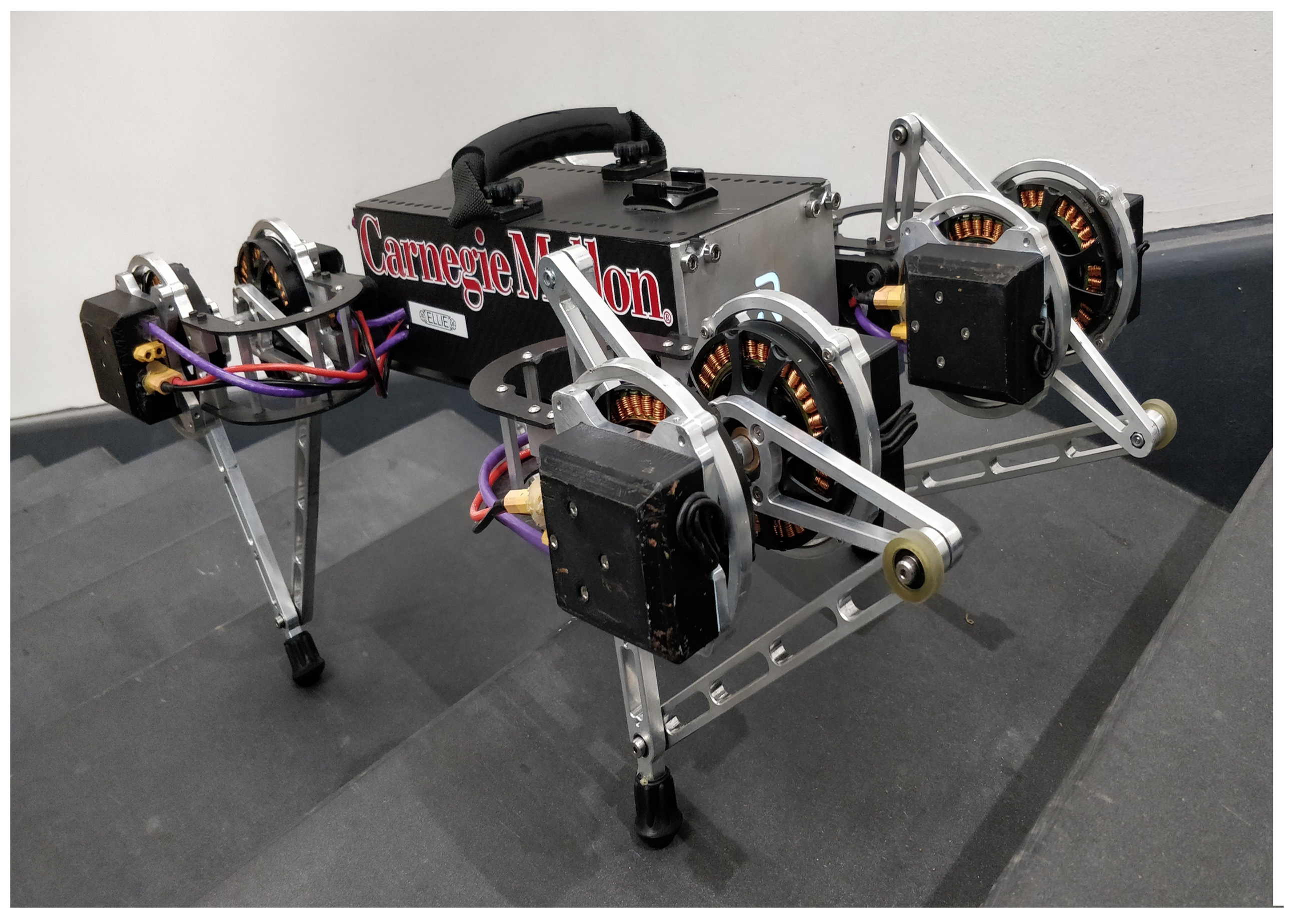

Figure 1: Minitaur quadrupedal robot

Framework

States = body position, body velocity, foot position

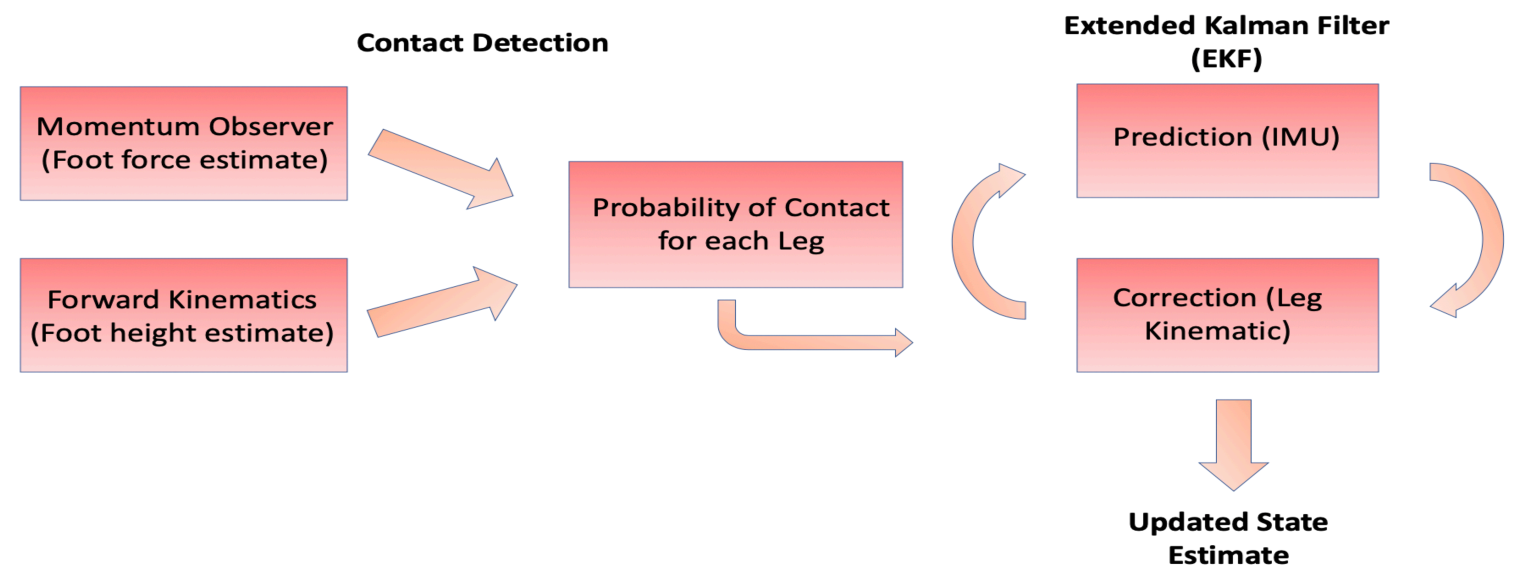

Figure 2: State estimation high level framework

Results

Figures below demonstrate the position and velocity tracking of the robot's COM vs the ground truth from motion capture system (MoCap) during a vertical jump and walk behaviors. The shaded green background identifies if the robot is in ground contact. As shown, we maintain a reasonably close estimate of the robot's states throughout both behaviors with the EKF state estimator. IMU or kinematic only estimates are insufficient to track robot states through contact transitions.

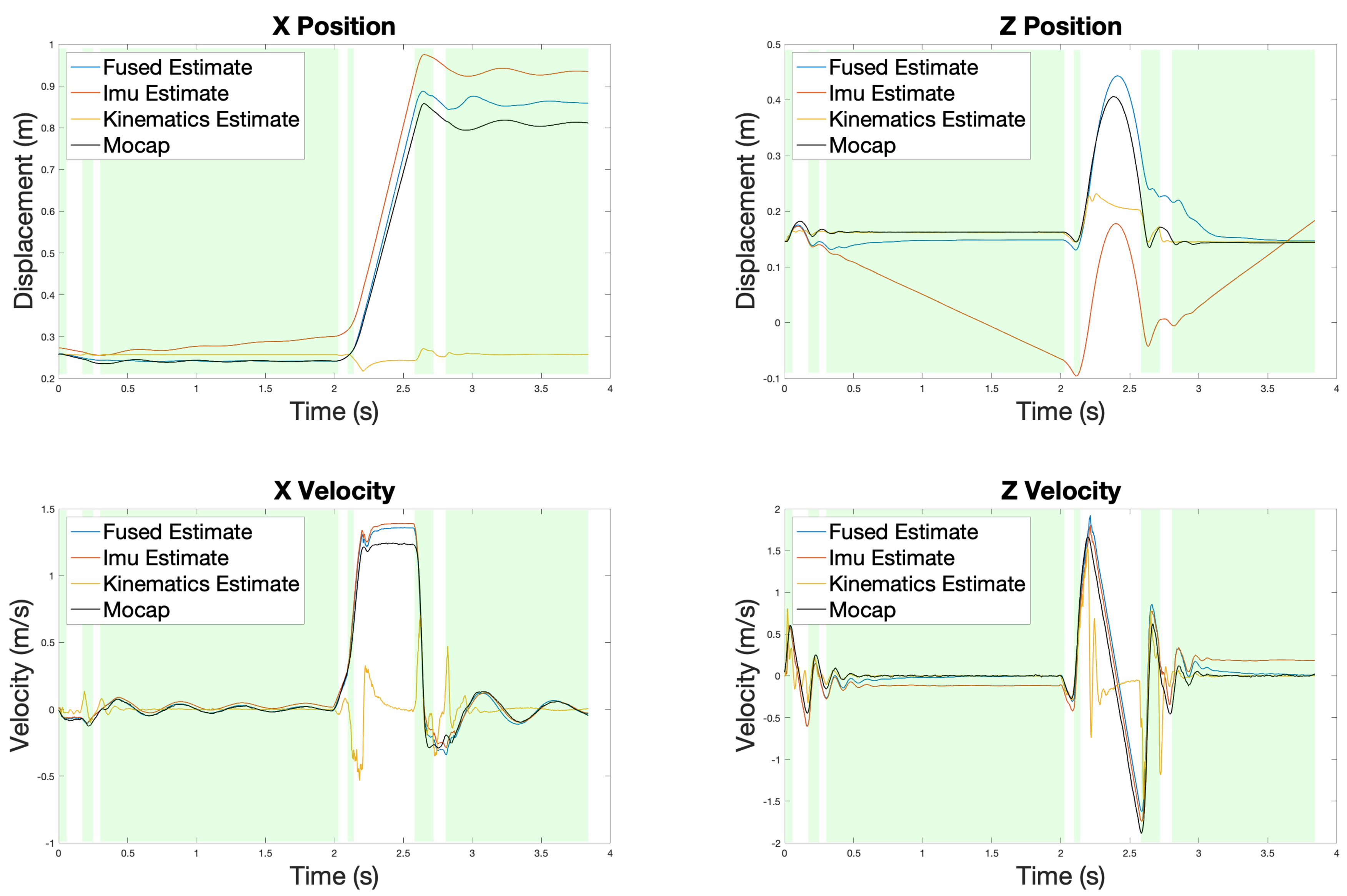

Figure 3: State estimation in jump behavior

In walk, the velocity estimates are close to ground truth unless the robot slips. However, the position drifts over time as expected, since there are no exteroceptive sources of measurements.

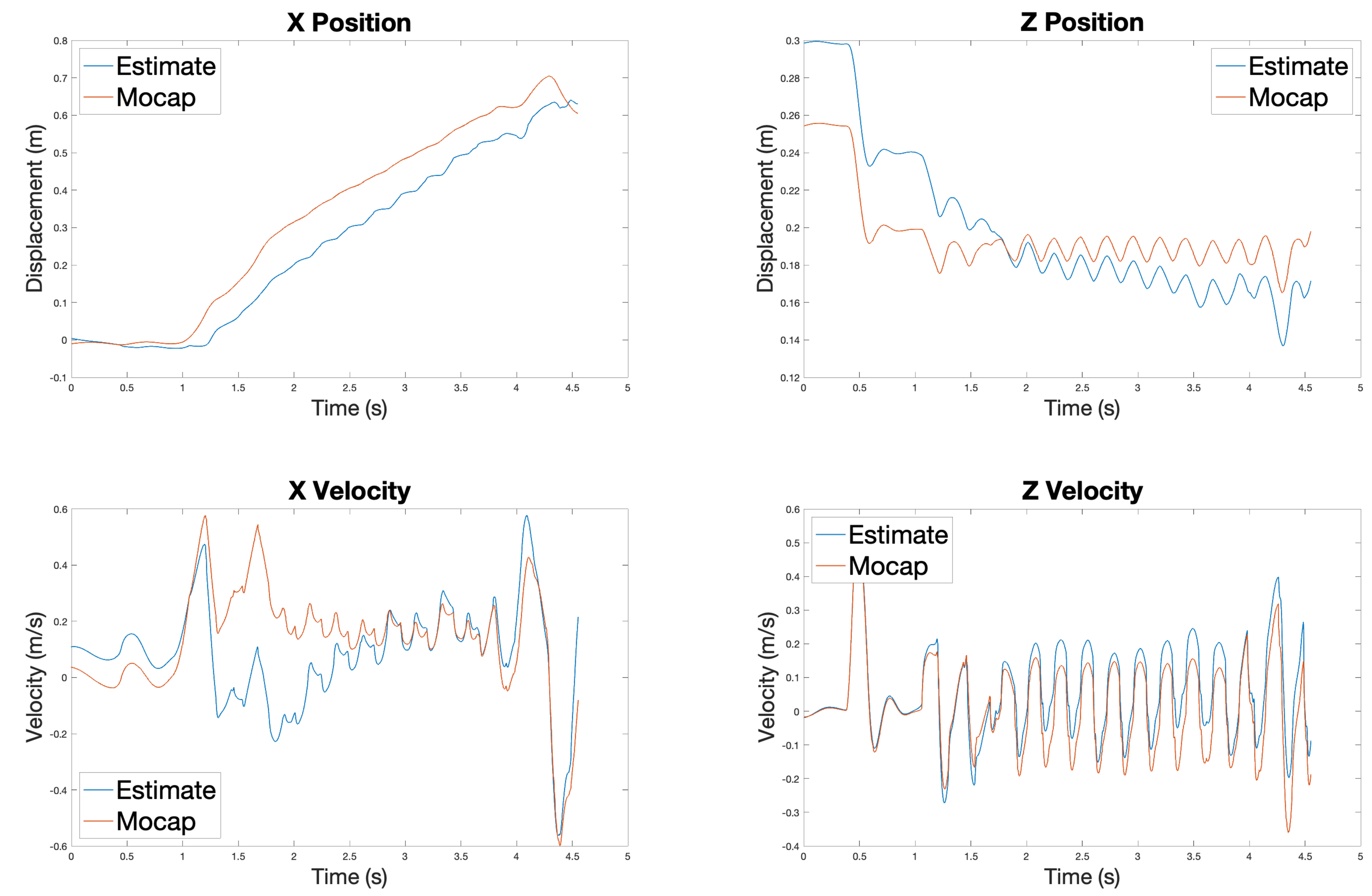

Figure 4: State estimation in walk behavior

Conclusions

- IMU or Kinematics odometry alone are not sufficient for reliable state estimation in legged robots
- Fusion of IMU and kinematics odometry performs reasonable given accurate contact detection
- The current filter is not robust to outliers during slip

Future Work

We hope to extend this estimation framework to an optimization-based moving horizon estimator that relies on a window of measurements and is more robust to measurement outliers and contact detection error induced by slipping.

References

[1] Bledt, Gerardo, et al. "Contact Model Fusion for Event-Based Locomotion in Unstructured Terrains." *2018 IEEE International Conference on Robotics and Automation (ICRA)*, 2018, doi:10.1109/icra.2018.8460904.
"State Estimation for Legged Robots: ConsistentFusion of Leg Kinematics and IMU." *Robotics*, 2013, doi:10.7551/mitpress/9816.003.0008.

[2] "State Estimation for Legged Robots: ConsistentFusion of Leg Kinematics and IMU." *Robotics*, 2013, doi:10.7551/mitpress/9816.003.0008.