SEROW: Legged Robot State Estimation

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I. Introduction

Floating base and Center of Mass (CoM) state estimation realizes a vital role in legged robot walking pattern generation and real-time gait stabilization [1]. In this article we present the State Estimation Robot Walking (SEROW) framework. The latter is a real-time legged robot state estimator that provides accurate 3-D estimates for the base and CoM and is publicly available as a ROS/C++ package at https://github.com/mrsp/serow

II. Framework

SEROW performs cascade state estimation [2]. Initially the 3-D base position, velocity, orientation and legs positions and orientations are estimated based on floating mass Newton-Euler dynamics and the Error State Kalman filter. Subsequently, 3-D CoM position, velocity and external force estimation is performed based on nonlinear centroidal dynamics and an extended Kalman filter. The composite framework effectively fuses the base's inertial measurement unit, kinematics and the leg pressure or force/torque sensors. To reduce the estimation drift SEROW can optionally consider external odometry measurements such as visual or lidar odometry [3].

III. Results

SEROW has been experimentally validated both in simulated and real-world experiments. Figure 1 demonstrates the estimation result for an uneven/rough terrain gait with the Valkyrie robot in Gazebo. For this $72s$ gait the average root mean square error for the base and CoM position and velocity was $0.0027m$ and $0.015m/s$ respectively, indicating low drift.

SEROW has been applied for real-time estimation with the WALK-MAN, COMAN+, TALOS and NAO humanoids and with the CENTAURO quadruped robot. Real robot experiments demonstrating the effectiveness of SEROW are available at https://youtu.be/unPCFaCRzkA

IV. Conclusion

SEROW is an open-source ROS/C++ real-time legged robot state estimator that provides accurate and robust estimates for important quantities commonly used in walking pattern generators and real-time gait control schemes. SEROW has been extensively evaluated with a variety of contemporary legged robots both in simulation and real-world experiments. Future work aims at improving SEROW's contact detection mechanisms and further reduce drift induced by leg slippage.

References

[1] S. Kuindersma, et al., "Optimization-based locomotion planning, estimation, and control design for Atlas," Autonomous Robots, vol. 40, no. 3, pp. 429–455, 2016.

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[3] S. Piperakis, D. Kanoulas, N. G. Tsagarakis and P. Trahanias, "Outlier-Robust State Estimation for Humanoid Robots," IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS), Nov., 2019, pp. 706-713.

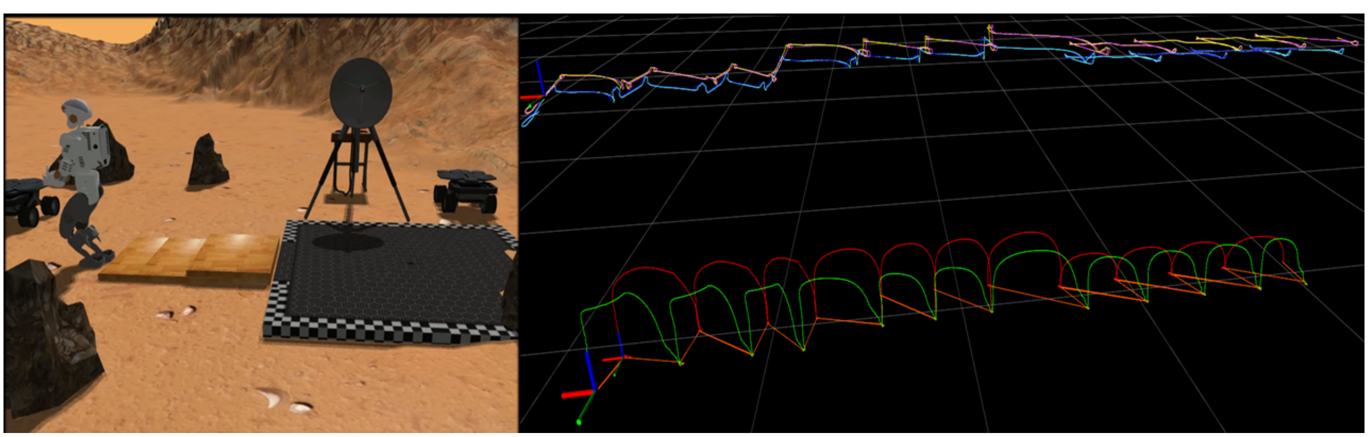

Fig. 1. **Left:** Valkyrie walking over uneven/rough terrain in Gazebo. **Right:** Yellow/Purple indicate the ground-truth/estimated base trajectories, Blue/Teal indicate the ground-truth/estimated CoM trajectories, Green/Red/Orange are the estimated left/right/support leg trajectories