Dynamically Equivalent Mechanism and Criteria for Multi-segmental Balancing

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1 Motivation

Legged mechanisms, such as humanoid robots and humans, as compared with wheeled locomotion, provides better flexibility, controllability, and collision-avoidance through configuration redundancy and increased mobility. One of the main costs of these advantages of legged mechanisms is instability and the risk of falling. Balancing is important not only for locomotion but also for general manipulation tasks, such as pulling, pushing, lifting, and throwing, of whole-body mechanisms. In particular, the functions of coordinated multiple body segments are critical in whole-body balancing.

2 State of the Art

Ground reference points have been introduced in the literature which provide necessary conditions for balancing, such as the zero moment point (ZMP) [1]. Several systems that help to predict or prevent falling have been developed by combining robotics and biomechanics research [2, 3]. There have been some attempts to define falling and the related terms [2, 4]. A recent comprehensive study on single-support capturability addressed a legged system's ability in a given state to come to a stop without falling by taking step(s) [2]. Most approaches to identify the balanced state domain in the current literature are based on specific control law, of which the performance is highly dependent on the given choice of controller design and parameters.

3 Own Approach

A balanced state manifold was constructed in the extended phase space of joint angle, joint velocity, and actuation limit, according to the proposed explicit forms of necessary and sufficient conditions of balanced state. A nonlinear constrained optimization problem was formulated, where dynamic models of the legged mechanism were incorporated, and was numerically solved within the iteration loops of partitioned joint angles and actuation limits. In addition to the system parameters, necessary conditions for balancing, such as the ZMP, positive normal reaction force, friction, and the ability to come to a final static equilibrium, were implemented as constraints for generality. A sequential quadratic programming method numerically solved for the velocity extrema within the complete feasible domain to construct the balanced state manifold as a viability kernel, which is a reachable superset of all possible controller-specific domains (Fig. 1).

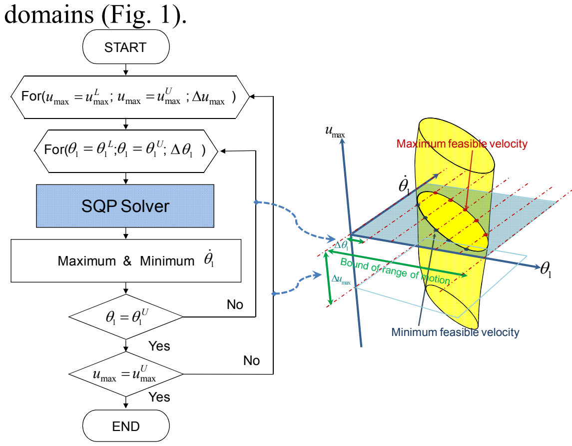

Fig. 1. Iterative formation of balanced state domain.

4 Current Results

The balanced state manifold of a multi-segmental model was constructed in the extended phase space, and the phase trajectories of biped walking motions are analyzed for both human and robot (Fig. 2).

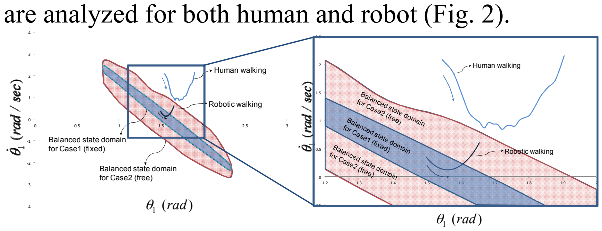

Fig. 2. Balanced state domain and gait phase trajectories.

5 Best Possible Outcome

A reduced-order model that is dynamically equivalent with general legged mechanism is developed and its multi-segmental effects on balancing is quantified.

References

[1] Mummolo and Kim (2013), *Robotica.*
[2] Koolen et al. (2012), *Int. J. Robot. Res.*
[3] Stephens and Atkeson (2009), *9th IEEE-RAS Intl Conf on Humanoid Robots.*
[4] Pratt and Tedrake (2006), *Fast Motions in Biomechanics and Robotics.*