Dynamic Bipedal Locomotion with Operational Space Control and Fast Reduced-order Planning

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I. Background

Practical bipedal locomotion control requires both a robust gait motion and the ability to navigate by changing its path. These needs call for fast low-level control computations and tractable mid-level trajectory planning. This is still an active and challenging research area. An HZD control framework has been implemented in [1] and a fast online planning for the Cassie robot is used in [2]. In this work, we use real-time optimization techniques to enable the Cassie bipedal robot to achieve robust and efficient locomotion behaviors with Operational Space Control and reduced-order model planning.

II. Methods

Our controller framework has three components: state estimation, trajectory generation, and a tracking controller (Fig. 1a). For state estimation, we use a contact-aided Kalman filter based on [3] to estimate the pelvis rotational and translational state. We used the filtered spring deflection on Cassie to detect foot contact with the ground.

Trajectory generation has two components: Center-of-Mass (CoM) motion generation and foot motion generation. We compute the desired CoM motion by solving a nonlinear trajectory optimization problem based on a 3D-SLIP model. The foot trajectory is generated in closed-form with a combination of user-supplied information (e.g. walking velocity, stepping height) and state feedback. The foot trajectory is composed of a combination of quintic polynomials and capture point calculations so the robot can swing its leg and maintain balance during walking.

Trajectory tracking is achieved with an operational space controller [2] defined by,

$$
\begin{aligned}
\underset{\ddot{q},u,f,\lambda}{\text{minimize}} \quad & ||A\ddot{q} + \dot{A}\dot{q} - \ddot{x}_{cmd}||_W^2 \\
\text{subject to} \quad & M\ddot{q} + C = Bu + J_f^T f + J_s^T \tau \\
& u_l \leq u \leq u_u \\
& ||f_x^i|| + ||f_y^i|| \leq \mu ||f_z^i|| \ , \ i = 1,2,3,4 \\
& J_s \ddot{q} = 0
\end{aligned}
$$

which minimizes the error between the desired acceleration and the robot CoM/feet accelerations. The resulting quadratic program is solved in real-time using OSQP.

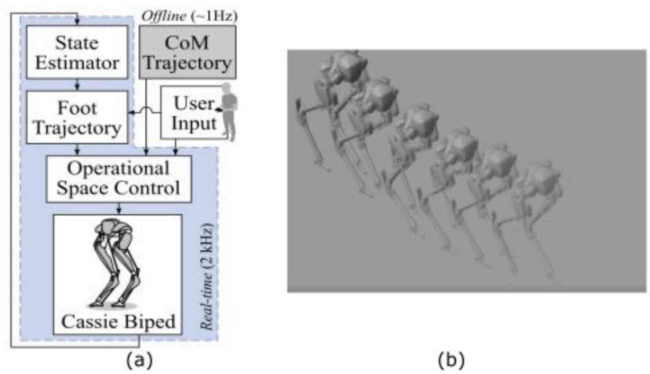

Fig. 1: (a): Our Cassie Control framework has three components: a contact-aided Kalman Filter, CoM and Foot Trajectory Generation, and an Operational Space Tracking Controller. (b): A stroboscopic sequence of a full-order Cassie simulation walking at 0.5m/s.

III. Results and Discussion

Currently, the proposed controller allows Cassie to step in place, walk at different speeds, and switch between these gaits in simulation (Fig. 1b). The top speed of this controller is currently 0.5 m/s. The real-time control loop operates at 2kHz and the offline trajectory planner computes solutions at a rate of $\sim$1Hz. In the future, we will implement this control framework on the “Tallahassee Cassie” hardware platform.

IV. Acknowledgment

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References

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