Hybrid Zero Dynamic Control Approach for a Curved Feet Bipedal SLIP

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I. MOTIVATION AND STATE OF THE ART

Spring Loaded Inverted Pendulum (SLIP) is one of the most common models which in addition to its simplicity, has similar behavior with real legged locomotion [1]. Addition of foot to this popular model results in more anthropomorphic behavior [2]. BSCF (Bipedal SLIP + Curved Feet) is the model used in this paper as shown in Fig. 1.

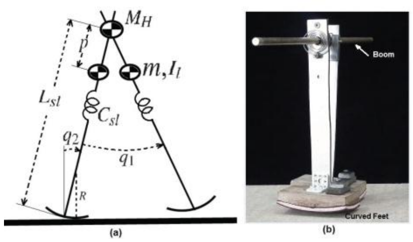

Figure 1: (a) The BSCF model state vector $\boldsymbol{q} = [\boldsymbol{q_1}, \boldsymbol{q_2}, \boldsymbol{L_{sl}}]$ (b) the curved feet robot with compliance in hip joint

We benefit the theory of virtual constraints and feedback control to achieve an asymptotically stable periodic walking gait which was never utilized for BSCF model yet.

II. OWN APPROACH

HZD-based controller uses virtual constraints for evolution of robot components which tend to create a hybrid invariant lower dimensional surface. Virtual Constraints (VC) are defined by determining appropriate outputs which their regulation to zero should be equivalent to stable walking. This regulation is achieved using feedback linearization. Like [3] and [4], Beziér polynomials are employed as desired function for evolution of robot configuration.

Selection of VC and walking configuration parameters coincides with an optimization problem which results in minimization of consumed energy per meter. The pre impact conditions e.g. q_2^- are important design parameters which influence energy consumption. The foot configuration parameters (like curve radius) is effectively dependent to these conditions.

The compliance in the BSCF model increases the degree of under-actuation which results in non-existence closed-form solution of Poincare return map. The stability of the closed-loop system is investigated by numerical solution of the restricted Poincaré map. The stability margin criterion is exploited from Jacobian linearization of the Poincaré map by the magnitude of the furthest eigenvalue from the origin (λ_{max}).

III. CURRENT RESULTS

The model parameters are adapted to a human with 80kg weight and 1.9m height and the foot radius is set to its optimum value $0.3L_0$ as said [2]. Bezier coefficients and pre impact conditions (angles and angular velocities) are computed by optimization. λ_{max} is less than 0.8 which results in slow convergence to limit cycle with low energy consumption. Faster convergence is possible with larger actuation. Fig. 2 shows the asymptotical stability of the limit cycles of leg angles. The region of attraction is acceptable.

IV. BEST POSSIBLE OUTCOMES

The next step is addition of compliance (rotational spring; see the robot in Fig. 1) in hip joint to store and regenerate part of required energy. With this attitude, the convergence rate (magnitude of the eigenvalues) can be considered in the cost function of the optimization and faster convergence to periodic orbit is achievable. Implementation of such a compliant HZD controller on our robot to walk with minimum energy consumption could be the further goal.

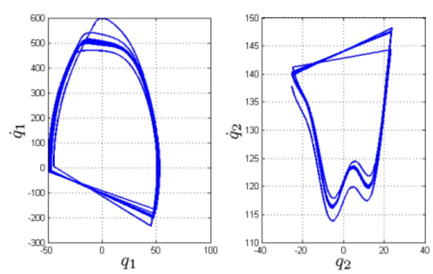

Figure 2: Convergence to limit cycles of leg angles

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