Human-like Walking with Compliant Legs

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Abstract—This work presents a novel approach to robotic bipedal walking. Based on the bipedal spring-mass model, which is known to closely describe human-like walking behavior, a robot has been designed that approaches the ideal model as closely as possible. The compliance of the springs is controllable by means of variable stiffness actuators. The controllable stiffness allows the gait to be stabilized against external disturbances.

I. INTRODUCTION

Humans are excellent walkers, able of energy efficient locomotion and quick adaptation to different terrains. This is achieved by a complicated musculoskeletal system, comprising many muscles, tendons and joints. However, it was shown in [1] that the human gait can be accurately modeled by a relatively simple bipedal spring-mass model. In particular, the model explicitly allows for a double support phase and reproduces the ground reaction force profiles that are observed in human walking gaits. Moreover, it was shown that the model encodes a variety of passive gait patterns, including running. In a more detailed study, presented in [2], it was shown that a large subset of the possible gaits are asymptotically stable, and that these gaits have a relatively large basin of attraction.

In [3], we proposed to extend the bipedal spring-mass model with variable compliance in the legs. By making the leg stiffness controllable, a control input is made available that can be used to stabilize a desired gait. Because the passive gaits are stable and locally attractive, control input is only required to converge to a neighborhood of the gait. Then, once convergence is achieved, no additional control is required to sustain the gait.

In this work, we describe the realization process of a bipedal walking robot, based on the principles of the bipedal spring-mass model with variable compliant legs.

II. THE BIPEDAL SPRING-MASS MODEL

Fig. 1a schematically depicts the bipedal spring-mass model. It consists of a point mass \( m \), and two massless telescopic springs with rest length \( L_0 \) and controllable stiffness \( k_i = k_0 + u_i, i = 1, 2 \). During the transition from single support to double support, the former swing leg is assumed to touch down at an angle \( \alpha_0 \). For appropriately chosen parameters \( m, L_0, k_0, \alpha_0 \) and initial conditions \( q(0), \dot{q}(0) \), the model will show a stable passive \( (u_i \equiv 0) \) gait trajectory \( q(t) \).

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In [3], we proposed a stabilizing controller that renders a passive desired gait stable against external disturbances by controlling the leg stiffness \( k_i \). The control law significantly increases the robustness of the gait. In particular, it was shown that the controller is successful in dealing with disturbances such as swing leg dynamics and impact forces that occur when legs with non-negligible mass are considered.

III. REALIZATION OF THE ROBOT

Currently, a robot is built that approaches the ideal bipedal spring-mass model as closely as possible. The bulk of the mass is located closely to the hip joint, while the legs are made of lightweight carbon fiber tubes. The stiffness of the legs is controlled by the novel vsaUT-II variable stiffness actuator [4]. Fig. 1b shows a CAD rendering of the prototype.

Currently, experiments with the prototype are under development, with the aim of validating the simulation results. In particular, the tests are designed to show that the variable stiffness actuation increases the robustness sufficiently to stabilize the gait of the walker.

REFERENCES