Modeling, identification and stability of a humanoid robot

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Abstract

In this work, we address modeling and identification of bipedal humanoid robots and conduct stability analysis of bipedal locomotion. We propose a theoretical framework for automatic modeling and identification of an arbitrary bipedal robot. Our approach is tested in experiments on the humanoid robot TUlip, shown in figure 1. Finally, we argue merits and limitations of the two most common methods for evaluation of stability of bipedal walking.

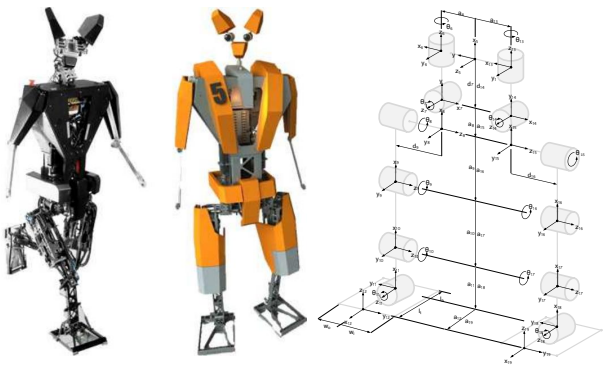

Figure 1: Humanoid TUlip: photo, CAD drawing and DH model

Using Denavit Hartenberg's convention for modeling robot kinematics, depicted in figure 1, we contribute an automatic algorithm for derivation of Lagrange-Euler equations of motions for a general bipedal humanoid robot. This algorithm is instantiated on TUlip. Furthermore, conditions for ground contact and impact expressions are derived and numerically integrated in a Matlab simulation together with equations of motion using the event detection method [1].

The model parameters of a humanoid robot can be identified in dynamic experiments. In this work, we propose a method for automatic conversion of the robot dynamical equations into a regressor form. Here, the dynamical equations encompass Lagrange-Euler equations of motion, equations of the actuator dynamics, friction and dynamics of the drive trains [1, 2]. Persistently exciting trajectories are optimized using the regressor of the resulting dynamical model, and these trajectories are used in experiments to estimate parameters of the robot TUlip. The estimated parameters are validated in experiments, and results are shown in figure 2.

The Zero Moment Point and Poincaré map methods have been applied for design and stability analysis of bipedal

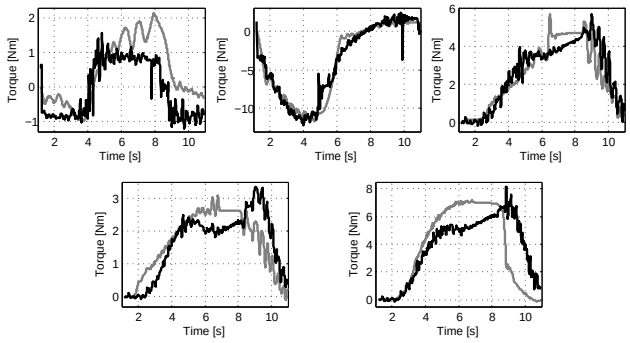

Figure 2: Validation of system identification: measured torque (grey) and model-based torque estimation (black)

walking. Illustrative results are shown in figure 3. Critical evaluation of both methods leads to the conclusion that these methods are neither sufficient nor necessary to guarantee stability of bipedal walking. Consequently, new theoretical formalisms are needed for proper qualification of bipedal locomotion stability and for synthesis of stable gaits [1].

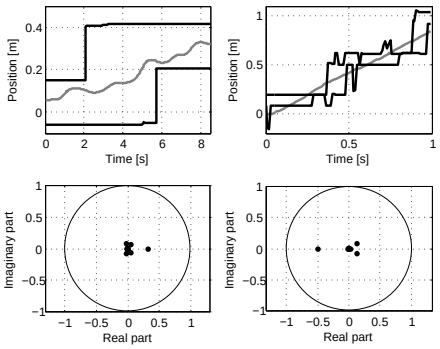

Figure 3: ZMP (top) and Poincaré (bottom) stability for ZMP based gait (left) and limit cycle walking gait (right)

References

[1] P.W.M. van Zutven. Modeling, identification and stability of humanoid robots, 2009.

[2] P.W.M. van Zutven, D. Kostić, and H. Nijmeijer. Parameter identification of robotic systems with series elastic actuators. In *8th IFAC Symposium on Nonlinear Control Systems*, pages 350–355, Sep. 2010.