ECCOMAS Thematic Conference on Multibody Dynamics
June 29 - July 2, 2015, Barcelona, Catalonia, Spain

Dynamic Simulation and Sensitivity Analysis of a Bipedal Robot with Contact Friction

Corner, S.[*], Zhu, Y.[*], Chai, Z.[*], Sandu, C.[*], Dopico, D.[*], Sandu, A.[*]

AVDL and CSL
107 Randolph Hall, Virginia Tech
Blacksburg, VA 24061, USA
scorner@vt.edu, yitao7@vt.edu,
zhi87@vt.edu, csandu@vt.edu,
sandu@cs.vt.edu

[#] Laboratorio de Ingeniería Mecánica
University of La Coruña
Mendizábal s/n
Ferrol, La Coruña 15403, Spain
ddopico@udc.es

Abstract

In addition to the dynamic simulation of multibody systems, different techniques have been developed to quantify the effects of the system parameters on the dynamic response. This can be accomplished through the development of novel sensitivity analysis methodologies. The co-authors of this paper have developed the adjoint variable method in the context of the penalty formulation [1], which performs sensitivity analysis and optimization for large and complex multibody systems. The present study focuses on multibody dynamics simulation, sensitivity analysis, and design optimization, for bipedal robots applications.

Dynamic walking simulation of a passive biped has been widely studied since 1990 [2-8]. Research from the literature conducted dynamic simulation of a passive bipedal robot using relative coordinates and Lagrange formulation. Although being generally used, this formulation presents some drawbacks. Formulations based on relative coordinates simulate the collision dynamics of the free foot with the ground using pre- and post-collision state-space. The collision is modeled as an inelastic impact with the assumption of angular momentum conservation.. Contact of the supported leg is simulated by a revolute joint, which prevents the foot from sliding [7].

Passive and active bipedal robots are used as case studies. A *passive* bipedal robot performs a walking motion without any actuator and controller, as opposite to an *active* bipedal robot, which uses feedback control and multiple actuators (typically redundant) at its joints. In order to enable any walking motion, the passive bipedal robot walks on a slope, with an initial velocity and legs angles.

Time (s) 0.00000
speed 0.75

Time (s) 2.16000
speed 0.75

Time (s) 5.00000
speed 0.75

Figure 1. Snapshot of dynamic simulation of bipedal robot walking with multi-point foot contact

The approach presented in this paper employs reference point coordinates. This approach allows a surface/multi-point contact model, as seen in Figure 1, in which the foot point contact is modeled as a spring-damper system combined with a friction model. From the snapshot, it is clear that the system is able to perform a stable walking, which converges to a stable limit cycle after several steps, as seen in the phase portrait from Figure 2. (The phase portrait technique is also employed in [8] to study the stability of a passive walker.)

In beginning, the stance leg (red) is placed on the slope and the swing leg (blue) is released with an initial angular velocity. At a certain moment, the knee-strike occurs when the swing leg straightens out, which leads to an instantaneous angular velocity change for both legs. Then, the swing leg swings as a single link before heel-strike to the slope. After the heel-strike, the knee is locked by a spring-damper system that connects the center of gravity of the thigh and shack and the swing leg switches to the stance leg. Then, the knee-strike from the swing leg leads to a small instantaneous angular velocity change for both legs again. Finally, after the heel-strike of the swing leg, the stance leg switches to the swing leg and start a new cycle again.

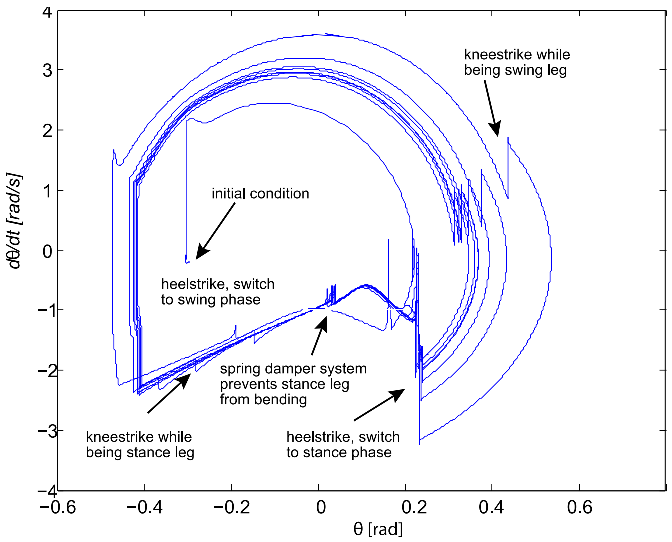

Figure 2. Phase portrait for the bipedal robot with multi-point contact foot

There are three main contributions of this study: First, it simplifies the dynamic simulation by avoiding changes of state-space variables in the equation of motion. Second, this approach makes the simulation more realistic since ground contact can now be simulated to account for the friction properties of the ground surface. Third, this approach allows the dynamic performance study and the optimization of a bipedal robot model, with implications in the selection of actuators and control design of active legged robots.

Acknowledgements

This work has been partially supported by NSF Award no. 1130667, by the Computational Science Laboratory (CSL), and by the Advanced Vehicle Dynamics Laboratory (AVDL) at Virginia Tech.

References

[1] Zhu, Y., Dopico, D., Sandu, C., & Sandu, A. (2014). “Dynamic Response Optimization of Complex Multibody Systems in a Penalty Formulation using Adjoint Sensitivity”. *arXiv preprint arXiv:1410.8422*.

[2] McGeer, T. (1990). “Passive dynamic walking”. *The Int. J. of Robotics Research*, *9*(2), 62-82.

[3] Collins, S., Ruina, A., Tedrake, R., & Wisse, M. (2005). “Efficient bipedal robots based on passive-dynamic walkers”. *Science*, *307* (5712), 1082-1085.

[4] Kuo, A. D. (1999). Stabilization of lateral motion in passive dynamic walking. *The Int. J. of Robotics Research*, *18*(9), 917-930.

[5] Collins, S. H., Wisse, M., & Ruina, A. (2001). “A three-dimensional passive-dynamic walking robot with two legs and knees”. *The Int. J. of Robotics Research*, *20*(7), 607-615.

[6] Garcia, M., Chatterjee, A., & Ruina, A. (1998, May). “Speed, efficiency, and stability of small-slope 2d passive dynamic bipedal walking”. *Proceeding of 1998 IEEE Int. Conf. on Robotics and Automation* (Vol. 3, pp. 2351-2356).

[7] Bagheri, A., Hajiloo, A. and Basiri, A. (2005, Sept.). "Determination of kinematic parameters of a passive bipedal walking robot moving on a declined surface by image processing." Proceedings of 5th WSEAS Int. Conf. on Signal Processing, Computational Geometry & Artificial Vision, Malta, (pp. 136-142).

[8] Tedrake, R., Zhang, T.W., Fong, M., and Seung, H.S. (2004). “Actuating a Simple 3D Passive Dynamic Walker”, *Proceedings of 2004 IEEE Int. Conf. on Robotics and Automation* (Vol. 5, pp. 4656-4661).