On closed-loop trajectory tracking for impacting mechanical systems

M.W.L.M. Rijnen, A. Saccon, H. Nijmeijer

Eindhoven University of Technology, Department of Mechanical Engineering,
Section Dynamics and Control Technology, P.O. Box 513, NL 5600 MB Eindhoven
phone +31-(0)40-2472811, e-mail m.w.l.m.rijnen@tue.nl

In the field of robotics, a clear shift in operating conditions is happening. Whereas robots were traditionally employed in fixed-base industrial settings, operating in a confined space, the current trend moves them to a changing environment where they interact with their surroundings with the goal of achieving human-like performance. These aspects present challenges in design, motion planning, perception, and control of the robots. The potential problems (e.g. instability) that come with impacts in the motion are commonly avoided by imposing that contact is established at negligible speed. However, such a choice limits the performance and possibility of motions. Think for example of dynamic manipulation of objects or of legged locomotion at high speed, i.e. running. Such motions inherently contain impacts at nonzero speed. This research aims at accurately controlling and performing impacting motions with mechanical systems.

Impacts generally result in sudden changes of velocity for the colliding bodies. Considering the small time scale of the impact, the resulting velocity changes are commonly modeled as velocity jumps, i.e. it is assumed that the impacts take zero time. Trying to make the system of interest follow a desired 'discontinuous' reference trajectory is challenging due to the fact the system will most likely experience the expected impacts at close, but not coincident, times. A controller, reacting to the resulting large error in velocity about the time of impact, may destabilize the system. The control strategy that we developed, and that goes by the name of reference spreading hybrid control [1,2], provides a practically viable solution to this problem by first partitioning the reference trajectory into the segments between state-jumps and adding a counter to each of them. Subsequently, each of the reference segments is extended smoothly by integrating the dynamics forward and backward. The choice of which reference branch to track now comes from counting the number of impacts the system has experienced and retrieving the segment with that counter.

The performance of the control method has been investigated by means of experiments on a one-degree-of-freedom setup consisting of a pendulum that is actuated using an electric motor and bounces off a block when in the vertical downright position. Moreover, the developed control strategy has been successfully applied in several simulation studies, e.g. on a complex (realistic) model of a humanoid robot [2] performing a motion with intermittent contact between its hand and a wall in front of it, while balancing on one foot (see Figure 1).

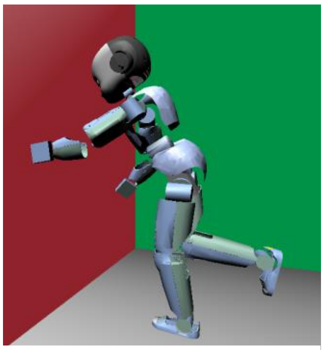

Figure 1: Snapshot of a robot impacting a wall

References

[1] A. Saccon, N. van de Wouw, and H. Nijmeijer, "Sensitivity analysis of hybrid systems with state jumps with application to trajectory tracking," in *53rd IEEE Conference on Decision and Control*, Los Angeles, USA, December 2014, pp. 3065–3070.
[2] M. W. L. M. Rijnen et al., "Control of humanoid robot motions with impacts: Numerical experiments with reference spreading control," in *IEEE International Conference on Robotics and Automation*, Singapore, May 2017, pp. 4102–4107.