Braking elastic joint robots in near-minimum time

Nico Mansfeld, Mehmet Can Özparpucu, and Sami Haddadin

I. Introduction

One important problem in human-robot interaction is to ensure the physical integrity of both humans and robots in case of unwanted or unexpected collisions. It is therefore crucial that a robot is able to detect collisions and take appropriate control actions to guarantee collision safety. For rigid robots and flexible joint robots such as the DLR LWR-III there exist well established collision detection and reaction schemes [1], [2]. For robots with intrinsic joint elasticity, however, only few reaction schemes have been proposed up to now, e.g. [3]. In this work, we consider the most intuitive strategy, namely stopping as fast as possible.

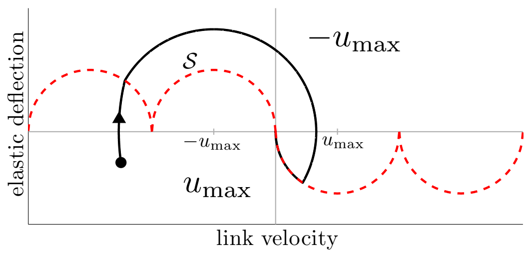

Fig. 1. Time-optimal braking of an elastic 1-DOF joint. Above the switching curve $\mathcal{S}$ one must apply the minimum motor velocity $-u_{\max}$, below it the maximum speed $u_{\max}$ to hit the origin time-optimally.

II. Approach

We assume that the motor dynamics are much faster than the link side dynamics and therefore model the motors as velocity sources with limited maximum speed. Braking a 1-DOF elastic joint with motor velocity interface in minimum time is a standard problem in optimal control theory [4]. From the system dynamics one can derive a switching curve that allows to determine the optimal motor speed given the current system state, i.e. elastic deflection and link velocity, see Fig. 1. For applying the method to n-DOF elastic robots we use a decoupling approach, see Fig. 2. First, the dynamics are transformed into decoupled space by making use of the generalized eigenvalue problem. Unfortunately, this transformation results in a coupling of the maximum/minimum motor velocities. To maintain the decoupling property, we decouple the control region in the next step. The optimal control law is then being applied to each SISO oscillator to obtain the desired motor velocities, which are finally being retransformed into original space.

Nico Mansfeld and Mehmet Can Özparpucu are with the Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Wessling, Germany, Sami Haddadin is with the Institute of Automatic Control, Leibniz University Hannover (LUH), Germany, {nico.mansfeld, Mehmet.Oezparpucu}@dlr.de, sami.haddadin@irt.uni-hannover.de

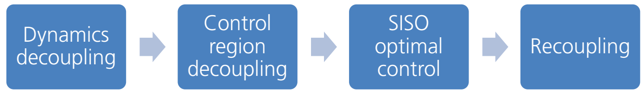

Fig. 2. Decoupling approach for braking an n-DOF elastic joint robot in near-minimum time.

III. Results

The controller is real-time capable and was implemented on a KUKA/DLR LWR4, where low joint elasticity was emulated by using joint impedance control. The joint stiffnesses and damping ratios were selected to be $K_{J,i} = 200$ Nm/rad and $D_i = 0 \ \forall i \in \{1, \ldots, 7\}$. Figure 3 shows the response due to an external collision. Strong oscillations can be observed for the undamped system while the velocities and deflections quickly decay to zero when the braking controller is being activated.

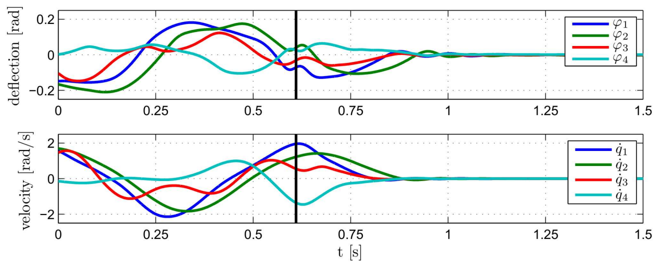

Fig. 3. Recorded deflections and velocities from the experiment with a KUKA/DLR LWR4. The black vertical line indicates when the braking controller is activated. We only show the signals of the first four joints, since the collision almost had no influence on the other joints.

References

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