End-Effector Trajectory Tracking Control of a Parallel Flexible Manipulator

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Abstract

End-effector trajectory tracking of flexible multibody systems is often a challenging task. This is due to the fact that flexible multibody systems possess less control inputs than degrees of freedom, i.e. they are underactuated. Thus, classical approaches known from fully actuated systems cannot be applied. The complexity might be further increased, if the multibody system includes additional constraints, e.g. due to kinematic loops or permanent contacts. Here, a parallel manipulator with flexible links is considered, see Fig. 1. The manipulator consists of two carts moving on linear axes which are actuated by linear servo-drives. On top of each cart one elastic link is mounted with a revolute joint. The mechanism consists of a long and short flexible arm. The two arms are connected to each other via a third revolute joint in the middle of the long arm, forming a so-called lambda kinematics. At the end of the long arm an end-effector mass is added. The end-effector point should follow a trajectory predefined in time and space. In addition, it is possible that the end-point is in contact with the environment. Thereby, trajectory tracking of the position of the end-effector point along a contact plane as well as tracking of the contact force is desired.



Figure 1: Model and test-bench of the considered parallel flexible manipulator.

This talk presents the control design for such a flexible multibody system. A control structure with two design-degrees of freedom is applied, combining feedforward control and feedback control. The feedforward control is computed based on an inverse of a flexible multibody model. For given desired output trajectories, e.g. end-effector point and/or contact force, the inverse model provides the required control inputs for exact output reproduction. An efficient model inversion approach for such multibody systems is the use of so-called servo-constraints, which are also called program-constraints or control-constraints [1, 2]. These can be seen as an extension of classical mechanical constraints and yield a set of differential-algebraic equations. This allows an efficient numerical solution without symbolic manipulations, which are often necessary in nonlinear control approaches. In addition, the use of servo-constraints allows the straightforward treatment of flexible multibody systems with various topologies.

Thus, systems in chain structure, with kinematic loops or with additional permanently closed contacts might be treated in a unified way.

The arising set of differential-algebraic equations describes the inverse model. The inverse model of the considered flexible manipulator includes a dynamical part, which is called internal dynamics in nonlinear control theory [3]. The solution method for this internal dynamics depends then on its stability. The considered system is so-called non-minimum phase if the end-effector point is used as system output [4, 5]. Thus, the internal dynamics is unstable. In this case forward integration yields unbounded states and inputs. However, a bounded solution can be computed from a boundary-value problem.

The feedforward control is then supplemented by additional feedback to account for small disturbances and uncertainties. On the one hand flexible manipulators require a large number of generalized coordinates to describe their dynamical behavior accurately. However, on the other hand, only a small subset of these values can be measured or reconstructed online. Hence, it is very challenging to use a state controller and output feedback might be more efficient. For vibration damping the arm deformation is determined using strain gauges and used as feedback to the servo-drives.

Besides the presentation of the theoretical basics of the control approaches and the underlying models, this contribution also presents the experimental test-bench and some experimental results, see also [6]. Only a small subset of the states can be measured and these measurements are afflicted with noise. Therefore, signal conditioning and state reconstruction are inevitable. Besides the positions of the linear motors, which are measured with incremental encoders, the deformation of the long arm is obtained by three strain gauges. In the control concept, only the states which are necessary for the feedback controllers, e.g. the car positions and velocities, are taken into account. Also, friction compensation plays an important role in motion control in general [7], and in the trajectory tracking of the presented parallel manipulator as well.

References

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