Inverse dynamics of a flexible 3D robotic arm for a trajectory tracking task

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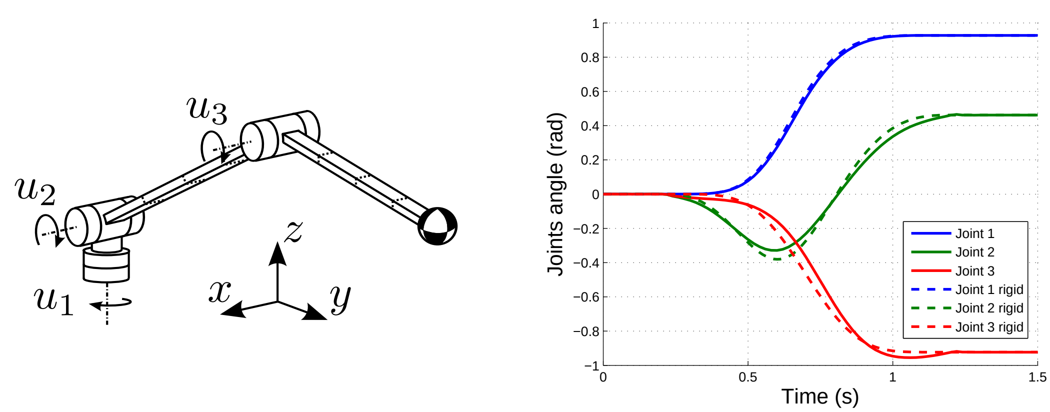
In the aim of improving safety and efficiency of robotic manipulators, links with reduced bulkiness and weight can be integrated to the robot. As a result, the manipulator becomes more flexible and might encounter vibration issues that have to be well controlled. Such flexible manipulators are said to be underactuated since they potentially have an infinite number of degrees of freedom (dof) and a finite number of actuators.

Flexibility can be dealt with by acting on the control system of the manipulator. Feedback action can be implemented to compensate for vibrations see, e.g., [1]. A second possibility is to model such flexible multibody system (MBS) in order to compute an input feedforward control signal that results in a vibration-free motion of the robot. Both the feedforward and the feedback control methods can be combined to achieve robust performances as presented in [2, 3].

To perform an end-effector trajectory tracking task, examples of feedforward commands for the manipulator would be the torques or the angular position of each of its joints. To find those inputs, the inverse dynamics of the MBS needs to be solved. In the case of a flexible system, some internal dynamics remains when the output trajectory is prescribed. The system is said to be non-minimum phase when this internal dynamics is unstable. If the inverse dynamics of a non-minimum phase system is simply solved using time integration algorithms, the resulting input control can be unbounded.

In order to obtain a bounded solution, a non-causal solution must be considered. A time domain inverse dynamics method is presented and tested for a linear system in [4]. For flexible nonlinear systems, a stable inversion method is presented in [5] and is applied in [6, 7]. An optimal control approach is proposed in [8] for 2D multibody systems. The present work extends this last method to solve the inverse dynamics of flexible 3D systems. The flexible MBS is modeled using nonlinear beam finite elements [9], rigid bodies and kinematic joints [10] formulated on a Lie group. The inverse dynamics is then stated as an optimal control problem where the amplitude of the internal dynamics has to be minimized. The prescribed end-effector trajectory is defined as an additional servo constraint of the optimization problem.



(a) 3D serial manipulator.

(b) Angular position controls of each joint.

Fig. 1: 3D serial manipulator modeled using 3 kinematic hinges, 8 beam elements and a point mass.

To demonstrate the capabilities of such method for 3D flexible systems, an experimental flexible robot is designed. The manipulator is made of two flexible aluminum beams with rectangular section and length of about 300 mm each. These links are actuated using three Dynamixel DC servomotors (MX and RX series). As a perspective, an experimental robot will be constructed in order to test various control strategies.

In this paper, a numerical model of the experimental manipulator shown in Fig. 1(a) is developed and used to support the mechanical and control design process. The input commands are the angular positions of each joint. The x,y and z positions of the point mass end-effector are considered as outputs. The trajectory that this end-effector has to follow is a circular arc in a plane parallel to the xz plane. Although the tracked trajectory is planar, the overall motion of the manipulator is three dimensional. Numerical computation of the inputs is done using two different hypotheses. In the first case, the manipulator is considered to be made of rigid links and the problem becomes equivalent to a computed torque control problem. The control inputs computed with this hypothesis are shown with dashed lines in Fig. 1(b). For the second case, flexibility is considered and the optimal control approach is used to compute control inputs, which are shown with plain lines in Fig. 1(b). The two different sets of inputs are then applied to the MBS model for a direct dynamics simulation. The resulting output trajectories are compared to show the improvement in tracking precision when flexibility is considered. As a perspective, an experimental robot will be constructed based on the model of the 3D manipulator and control inputs will be tested.

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