Trajectory optimization for 3D robots with elastic links

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Abstract

Lightweight robotic manipulators can improve the productivity of industries. Reducing the mass of current bulky robotic arms can indeed lead to higher operational speed, while consuming less energy and being safer. However, by reducing the mass, vibration and flexibility effects become more apparent and have to be considered in the control of the robot motion.

Flexible manipulators are said to be underactuated since they have a finite number of actuators and potentially an infinite number of degrees of freedom. Such manipulators possess an internal dynamics which can be unstable when end-effector trajectory tracking is wanted. The flexible multibody system is then said to be non-minimum phase. In order to solve the inverse dynamics of such system, stable inversion methods or optimization methods can be used.

The stable inversion method described in [1] allows us to obtain a bounded and non-causal solution for the inverse dynamic problem. It requires to solve a boundary value problem which contains the ordinary differential equation (ODE) of the internal dynamics of the system. The stable inversion technique involves symbolic manipulation of the equations of motion in ODE form and can thus be quite cumbursome for complex systems with closed kinematic loops. In order to avoid these manipulations, an extension of the stable inversion method was proposed in [2] so that the algorithm can be applied to solve the internal dynamics formulated as a differential-algebraic equation (DAE).

Alternatively, in [3], the inverse dynamics of planar flexible manipulators is successfully solved using an optimal control strategy. Serial and parallel manipulators are modeled using a finite element method and their inverse dynamics is solved using the direct transcription method. Compared to the stable inversion method, this technique does not require the formulation of boundary conditions at the beginning and at the end of the trajectory. Its implementation is thereby significantly simplified.

In this work, the optimal control strategy is extended to 3D manipulators. A Lie group formalism is adopted in order to deal with 3D motions. As shown in [4], this formalism leads to time integration algorithms that can achieve similar accuracy as classical methods while reducing significantly the non-linearities of the equations of motion. For the sensitivity analysis, a semi-analytical method such as the direct differentiation method described in [5] is implemented to take advantage of the simpler form given by the Lie group formulation.

In order to demonstrate the behavior of the algorithm, a serial manipulator is modeled using a 3D finite element model. The resulting inverse dynamics in DAE form is considered as an optimal control problem where the objective function to be minimized is the integral of the squared amplitude of the internal dynamics over the trajectory.

References

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