



A model predictive control approach for time optimal point-to-point motion control

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ARTICLE INFO

Article history:

Received 9 November 2010

Accepted 24 July 2011

Available online 3 September 2011

Keywords:

Model-based control
Time-optimal control
Mechanical systems

ABSTRACT

This paper presents a new model predictive control method for time-optimal point-to-point motion control of mechatronic systems. The formulation of time-optimal behavior within the model predictive control framework and the structure of the underlying optimization problem are discussed and modifications are presented in order to decrease the computational load of the numerical solution method such that sampling rates in the millisecond range and long prediction horizons for large point-to-point motions are feasible. An extensive experimental validation on a linear motor drive and an overhead crane setup demonstrates the advantages of the developed time-optimal model predictive control approach in comparison with traditional model predictive control.

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1. Introduction

Most mechatronic systems are controlled using linear feedback controllers, e.g. traditional PID controllers [1] or more advanced model-based controllers, like e.g. H_∞ robust controllers [2] or internal model controllers [3]. Their main advantage is their simplicity and for numerous applications, linear controllers are perfectly suited and can be well-tuned. Their main disadvantage however, is their inability to account for constraints on inputs, outputs and states. Hence linear controllers can not cope well with applications where time optimality is required within stringent input constraints, except if they are combined with reference trajectories that take into account these constraints. Two different time-optimal applications can be considered: time-optimal trajectory tracking like e.g. [4] and time-optimal point-to-point or setpoint control. This paper considers the latter application, which means that a desired endpoint is defined without specifying an intermediate trajectory. Hence, in order to achieve time-optimal point-to-point motion with a linear controller, a point-to-point reference trajectory has to be designed first. Demeulenaere et al. [5] present a polynomial spline based reference trajectory optimization approach. The method can be applied to any linear time invariant system, input, output and state constraints can be accounted for, and time-optimality is achieved by solving a sequence of feasibility problems. Also, Henrion and Lasserre [6] present a method to compute a polynomial reference trajectory which can take into account constraints on inputs and outputs. Although the formulated trajectory optimization problems are either linear, quadratic or LMI problems [7], and hence can be solved typically within one second,

the method is an off-line method, meaning that either all reference trajectories have to be optimized beforehand, or references are generated during motion by interpolating between a limited set of optimized trajectories. In the latter case, time-optimality and constraint satisfaction cannot be guaranteed. Besides this off-line approach, several on-line approaches exist, however none of them can guarantee time-optimality and constraints satisfaction for all possible point-to-point motions. Input shapers [8–12] are linear filters that generate reference trajectories aiming at minimal residual vibrations. These filters can be designed to yield time-optimal behavior for one particular reference step. However, if they are applied to smaller or larger reference steps, the resulting reference trajectories are either conservative or yield input constraint violation. Alternatively, to obtain near time optimality over a wider range of step references, these prefilters which compensate for higher order vibrations modes can be combined with an optimized rigid body reference trajectory [13]. [14,15] present strategies that calculate reference trajectories which satisfy constraints on velocity, acceleration and eventual higher derivatives. Hence, these methods cannot take input constraints into account directly. In addition, time-optimality can only be guaranteed for specific point-to-point motions that e.g. include a constant velocity part and for systems of which the order is limited to four. None of these on-line methods can cope well with the situation where a new reference step is requested while still executing the previous step. Model predictive control (MPC) is more appropriate for these applications since it can take system constraints explicitly into account. MPC algorithms calculate future control actions by solving at each sampling time an optimization problem specified over a certain prediction horizon for a given system model, a given estimate of the current system state and reference signal, and taking into account constraints on inputs, outputs and states. The main

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