Machine-In-the-Loop Control Optimization

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1 Introduction

Control design is an important issue in the development of high-precision motion systems. To meet the increasing performance requirements, it is often necessary to extend the traditional two-degree-of-freedom control structure with additional control-related functionality, such as filters and tables. With this increasing flexibility and complexity of the control system, it is necessary to develop tuning methods for an increasing number of parameters. The current methods can be divided into manual control design and off-line model-based control design, which incorporate several disadvantages. We believe that these shortcomings can be overcome by Machine-In-the-Loop (MIL) control optimization.

2 MIL Control Optimization

The main idea behind MIL control optimization is to formulate the control problem as an optimization problem in which the objective function is evaluated and optimized on the real system. This is a rather general concept, which can be used to optimize many different elements of a typical control system. Desired properties of this concept are: ability to adapt to changes in system dynamics, that it achieves optimal performance given the design freedom, automated procedure, applicability of the optimized controller to a variety of tasks, guaranteed convergence and that model knowledge can be limited to simple/cheap models.

In literature, several methods are described that relate to MIL control optimization. Examples of these methods are Lifted Iterative Learning Control (ILC) [1] and Iterative Feedback Tuning (IFT) [2]. It is observed that these methods solve specific control problems, whereas the objective of all methods is to minimize the tracking error. Moreover, they share many tools/approaches. This observation suggests that a generalized approach can be proposed for the solution of a much larger range of control problems than those covered by the mentioned techniques.

3 Generalized Approach

Our research on MIL control optimization has started off by attempting to define a general step-wise approach, which can be applied to solve a large class of practical control problems. The following are identified to be the main steps:

Problem statement The problem statement is given by the objective, typically a minimization of the tracking error, followed by a choice for the control element that is used to achieve this objective. It is necessary to include knowledge on the true operation of the system, leading to a description of the nominal system behaviour as well as changes therein (position-dependency, setpoint changes).

Choice of structure The choice for the structure of the control element results in a set of coefficients that will be used for optimization. Important aspects that influence this choice are the system dynamics and the reference trajectory.

Choice of objective function Regarding the objective function, it is important to realize that feasibility and predictability of MIL control optimization strongly depend on the nature of the objective function. In ILC and IFT, quadratic objective functions are common. It is recommended to choose the objective function such that a convex program results.

Choice of optimization algorithm Generally, the selected coefficients are unconstrained, which implies that Newton’s method can be used. Newton’s method requires a step length and a search direction, which in turn requires the gradient and the Hessian. Question is whether the latter quantities must be computed by using model knowledge (ILC) and/or measurement data (IFT). Another important issue is that measurement noise may influence convergence.

In this research, we intend to study these steps in detail.

4 Example Problem

A low-order feedforward controller is well-known as a standard industrial feedforward controller. It often consists of different parts, related to the velocity, the acceleration, the jerk and the snap (derivative of jerk) of the setpoint. The main difficulty is the tuning of the coefficients of the feedforward parts, which is done by manual tuning. Obviously, MIL control optimization can be used to realize optimal tuning and to adapt to changes in the system dynamics.

References
