Feedforward and Learning for LTV Systems
with Application to a Position-Dependent Printer

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1 Background

Systems performing repeating tasks can achieve high performance by learning a feedforward task through iterative learning control (ILC). Examples of such systems include assembly robots, wafer stages [2], and printing systems as in Figure 1. These systems perform motion tasks, as a result position-dependent dynamics occur. If these position-dependent dynamics are not appropriately addressed in control design, performance degradation or even closed-loop instability may occur.

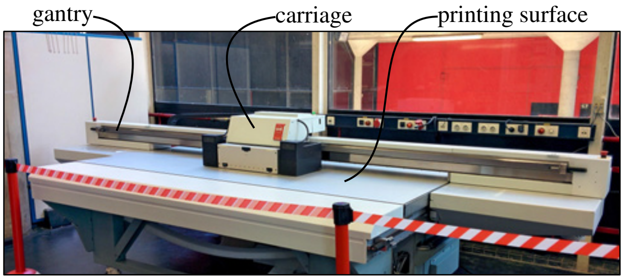

Figure 1: Océ Arizona 550 GT flatbed printer at the TU/e Motion Lab. The movements of the carriage and gantry introduce position dependence.

2 Problem formulation

Although position-dependent systems are nonlinear, ILC for these systems is often based on linear time-invariant (LTI) models, potentially limiting the performance. The goal of this research is to design suitable learning and feedforward algorithms for position-dependent systems with large tasks ($N \approx 100,000$ samples). Conventional lifting techniques are feasible, but computationally inefficient as the computation time scales with $\mathcal{O}(N^3)$, with N the task length, see also Fig. 3. For example, computations for a task of $N = 100,000$ samples take 36 hours.

3 Proposed method

In the proposed method, the position dependence of the system is transformed to time variance by linearizing the system around the given trajectory. The resulting ILC optimization problem for the linear time-varying (LTV) system is solved computationally efficient using Riccati equations. The proposed solution has strong connections to LQ tracking [1] and stable inversion [3].

4 Results

The importance of addressing position dependence is apparent in Figure 2. The performance with LTI models strongly depends on the position of linearization: convergence is slow (+), or additional robustness is required (∗) to guarantee convergence, at the cost of performance (×). In contrast, the exact LTV model (○) achieves one-step convergence.

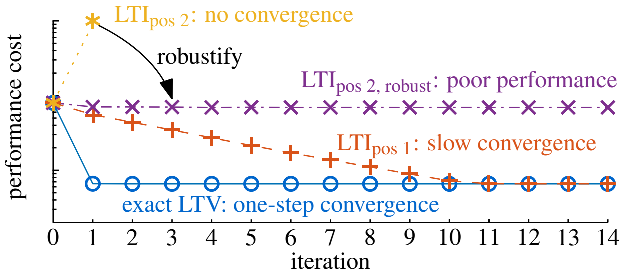

Figure 2: Taking position dependence into account through LTV models yields superior performance over LTI models.

The computation time for the proposed method is significantly smaller than for the conventional method: $\mathcal{O}(N)$ vs $\mathcal{O}(N^3)$, see Fig. 3. For $N = 100,000$ samples it takes only 23 seconds to compute the solution, for both LTI and LTV.

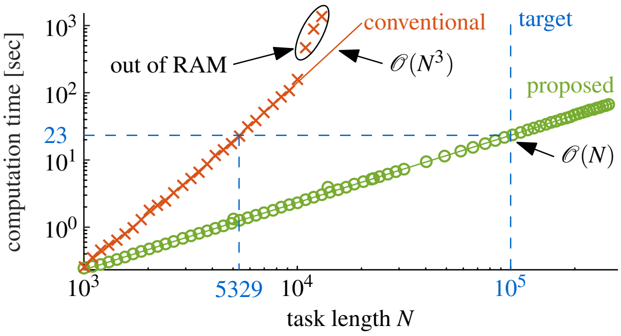

Figure 3: The proposed method significantly reduces the computation time compared to the conventional method.

Ack: The authors thanks Joost Bolder for his contributions.

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