PhD in Computer and Control Engineering
XXXIV cycle

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# Recursive Set-Membership Estimation for LTV systems and Application to DDC

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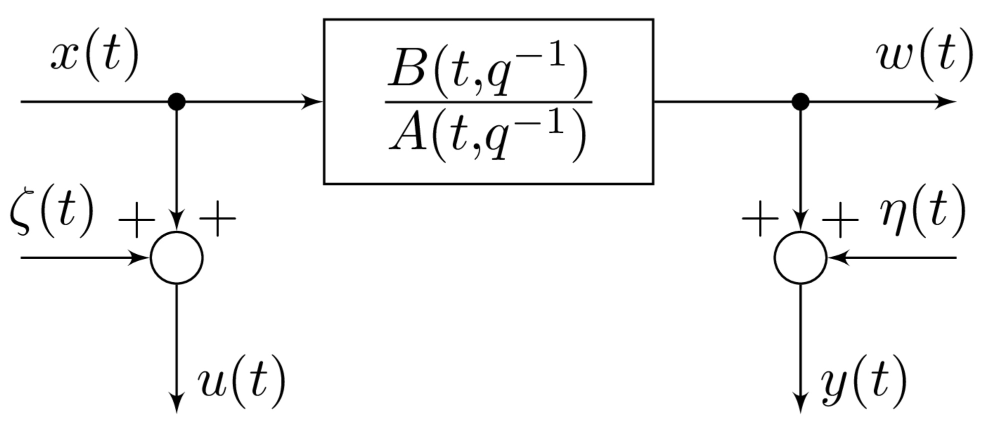
## 1. Introduction

System identification and control of linear time varying (LTV) systems are topics of great interest in the control community. This is motivated by the fact that most real-world systems are usually time varying. These problems have been addressed thoroughly in the literature under the classical framework, where the measurements are assumed to be corrupted by noise that is described statistically, and the bounded-errors or set-membership (SM) framework, where uncertainties are assumed to belong to a given set. The contributions that have addressed this problem in the SM framework have considered the case known as equation error, where the sources of uncertainty are all taken into account by a single error term added to the difference equation. The case when both input and output measurements are affected by bounded noise, referred to as the errors-in-variables (EIV) structure, remains an open topic.

## 2. Objective

The objective of the PhD work is to develop new algorithms for identification and control of LTV systems in the SM framework, considering an EIV setting. The main difficulty of the addressed problem(s) is that, due to their structure, we need to solve nonconvex optimization problems whose global optimum can be approximated by means of semidefinite programming (SDP) relaxation techniques. However, due to the high computational burden for solving SDPs, they are not effective when the estimation needs to be performed in real-time (online). Starting from this last point, we propose novel algorithms for the addressed problem(s), that can compute the solution of the EIV problem(s) in a small amount of time, while assuring global optimality.

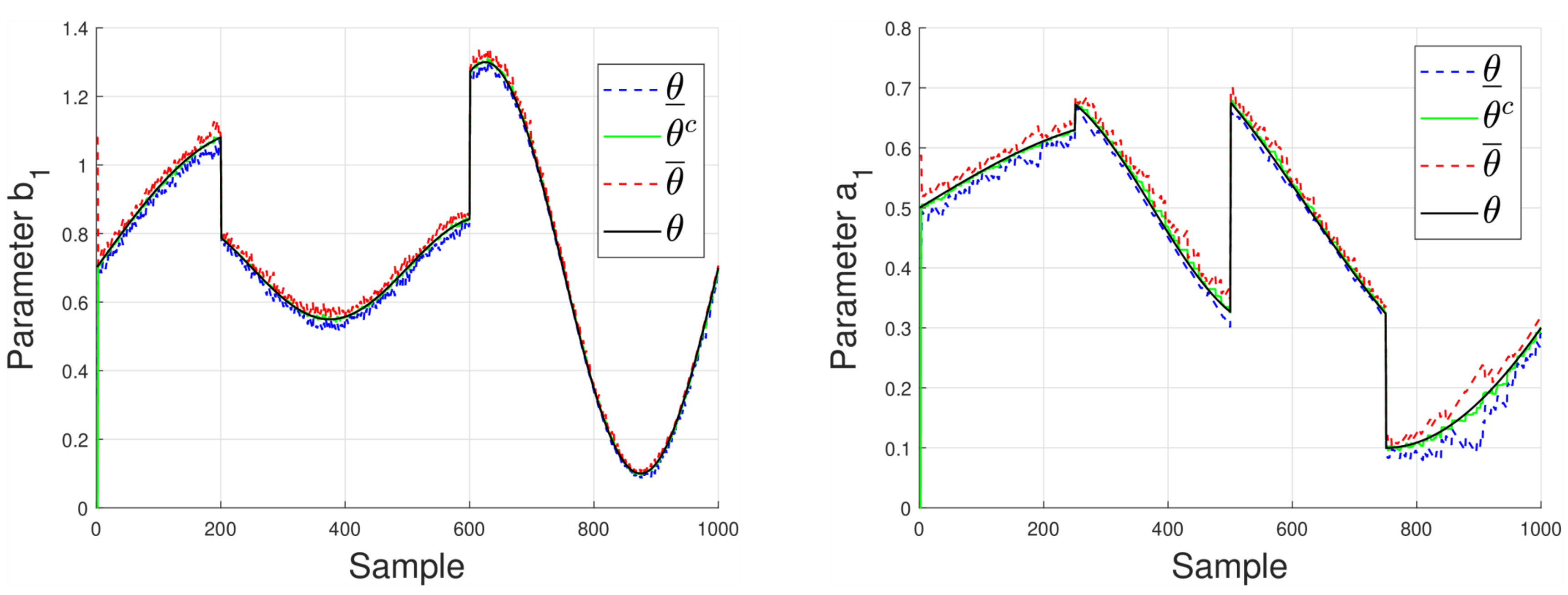
## 3. Recursive SM for LTV systems [1],[2]




We address the problem of computing the parameter uncertainty intervals (PUIs) for LTV systems. Two cases are considered:

(a) Systems with bounded variation.

(b) Systems with abrupt parameter changes.




**Algorithm 1** Two-stage algorithm

**Input:** (a) Upper bound on variation in case of no jump $\Rightarrow \Delta^*$

(b) Initial parameter estimates at $t=0 \Rightarrow \underline{\theta}(0)$, $\overline{\theta}(0)$

**Output:** Online estimate of the PUIs

1: **for all** $t = 1, 2, \dots$ **do**

2: Acquisition of the current measurements $u_t$, $y_t$

3: **if** (system includes parameters with jumps) **then**

Solve: $\min_{\theta(t)\in\mathcal{D}_\theta(t)} \sum_{j=1}^{n_p} \Delta_j(t)$ ($\ell_1$ norm of $\Delta(t)$)

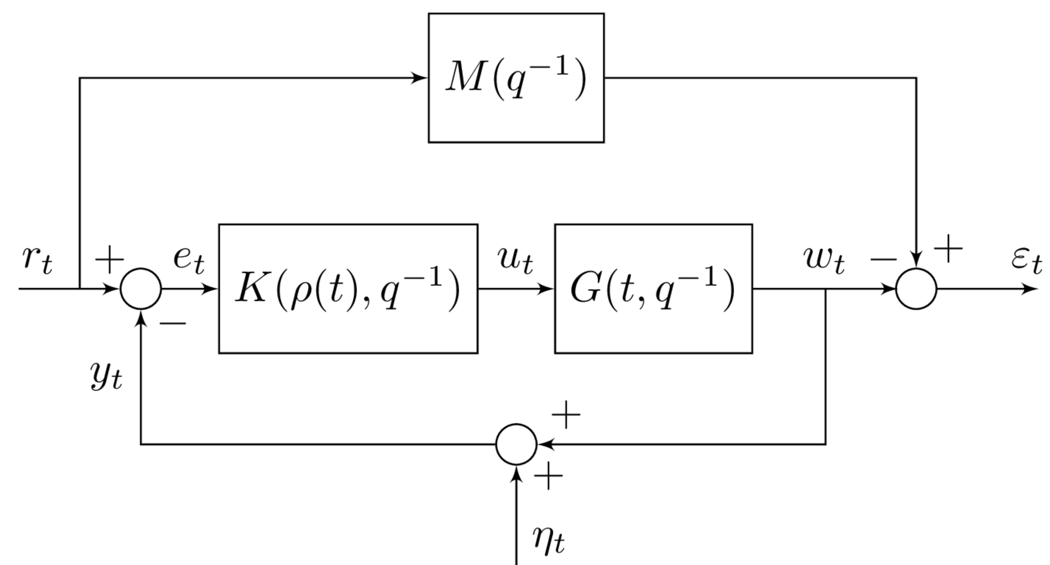
4: **end if**

5: To compute the PUIs,

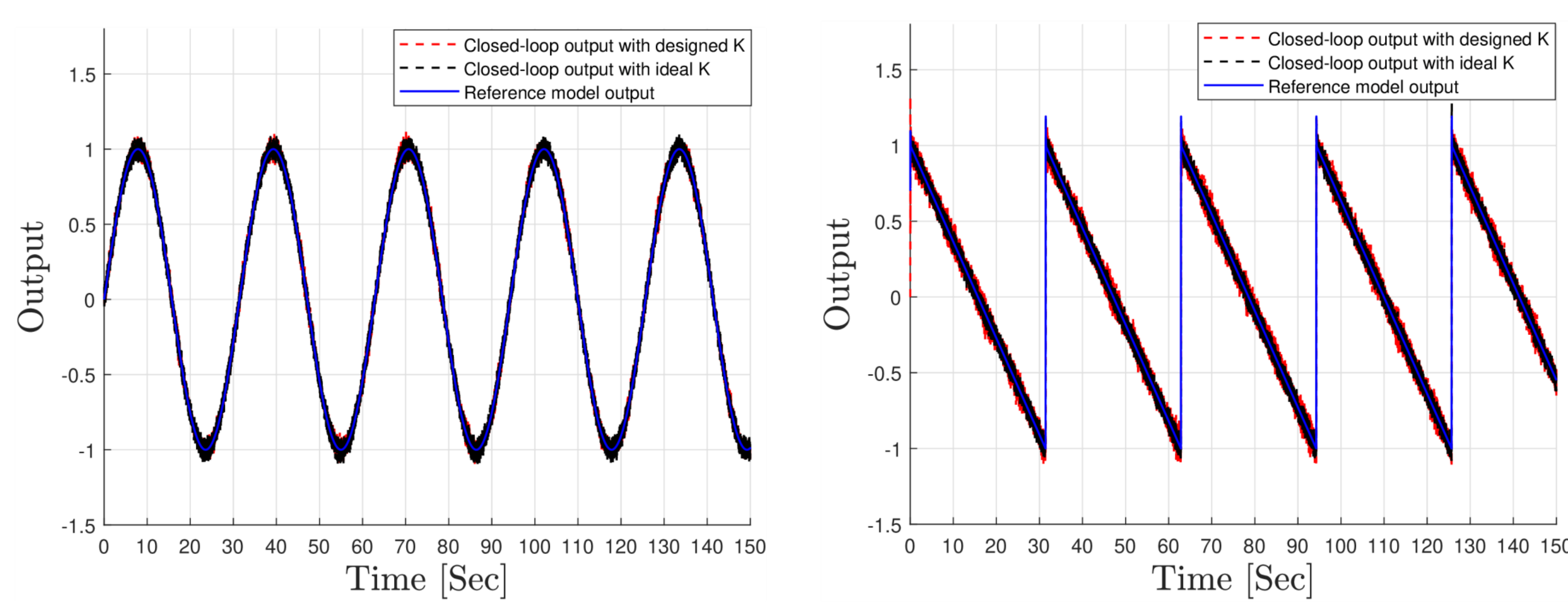
Solve: $\underline{\theta}_j(t) = \min_{\theta(t)\in\mathcal{D}_\theta(t)} \theta_j(t)$, $\overline{\theta}_j(t) = \max_{\theta(t)\in\mathcal{D}_\theta(t)} \theta_j(t)$.

6: **end for**

## 4. Adaptive data-driven control [3]




Adaptive control is one of the most common approaches for controlling LTV systems, thanks to its ability to account for variations in the system to be controlled. In this work, we propose an adaptive scheme for controlling LTV systems, affected by measurement noise, without assuming any mathematical model for the plant. The controller parameters are tuned in real-time such that the closed-loop behavior matches, as close as possible, that of a given reference model M. In particular, we pick the controller with the minimum parameter variation among the set of controllers, solving the model-matching problem.




## 5. References

1. Cerone, V., Fosson, S. M., Regruto, D., **Abdalla, T.** (2020). A recursive approach for set-membership EIV identification of LTV systems with bounded variation. In 2020 59th IEEE Conference on Decision and Control (CDC) (pp. 3951–3956).

2. Fosson, S. M., Regruto, D., **Abdalla, T.**, Salam, A. (2021). A convex optimization approach to online set-membership EIV identification of LTV systems. In 2021 60th SICE Annual Conference (pp. 1442-1447).

3. **Abdalla, T.** (2021). Adaptive Data-Driven Control for Linear Time Varying Systems. Machines, 9(8), 167.