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RESEARCH INTERNSHIP
Cnam Paris | 6 months

Optimization of Luenberger-Based Interval Observers for Effective Fault Detection

Possibility of pursuing a PhD after the internship

Supervisors: Thach Ngoc Dinh (ngoc-thach.dinh@cnam.fr) and Tarek Raïssi (tarek.raissi@cnam.fr) (Cnam, France)
Collaborator: G. Q. Bao Tran (gia-quoc-bao.tran@ieee.org) (UIUC, USA)

Project Description

Interval observers, unlike asymptotic observers, give component-wise upper and lower bounds of the true state of a dynamical system [1,2]. They have a wide range of applications in control and fault detection [4,5]. Designs of these observers for linear time-invariant (LTI) systems using positivity have been proposed in [1,2], but are in general time-varying. Recently, we have proposed the first time-invariant designs for LTI systems [3], called the **Luenberger-based** design. However, only the feasibility problem was solved, and the resulting bounds can still be large and far away from the true state, which limits performance and applicability.

The first objective of this internship is to investigate an **optimization scheme** for LTI interval observers. The design in general involves solving a Sylvester equation for a matrix transformation, into positive and stable coordinates. This must be integrated as a constraint of an optimization problem, involving an appropriate cost function quantifying the observer bounds after settling (neglecting transient effects). However, this problem is non-convex, non-smooth, and in general high-dimensional. Appropriate methods, such as reformulations that exploit the structure of the problem to **reduce its dimension** or **make subproblems convex**, combined with non-smooth or derivative-free optimization, must be investigated. The intern will formulate this optimization problem, exploit its invariances to obtain an equivalent problem of reduced complexity in which, for a fixed transformation, the observer gains follow from linear programs, and develop a numerical scheme guaranteeing that iterations yield a valid interval observer. The resulting designs will be compared with the feasibility-based design of [3] on benchmark examples, in terms of steady-state bound width, convergence speed, and numerical conditioning.

The second objective is to explore **fault detection** using the optimized interval observer. In the fault-free case, the observer provides guaranteed bounds on the output, so a fault can be detected as soon as the measured output leaves these bounds. Tighter bounds allow smaller faults to be detected and shorten the detection time. The intern will formalize detectability conditions in terms of the fault magnitude and the steady-state width of the bounds, and quantify the gain obtained with the optimized observer compared to the feasibility-based design of [3]. Extensions to **fault isolation**, for instance with banks of interval observers each optimized to be insensitive to a given fault, may also be considered.

Tentative Timeline

Month 1: Literature review on interval observers, positive systems, and non-smooth optimization; familiarization with the design of [3].

Months 2–3: Development of the optimization problem and of numerical schemes to solve it, with implementation and comparison on benchmark examples.

Months 4–5: Application of the optimized interval observer to fault detection and evaluation in simulation.

Month 6: Final analysis, preparation of the internship report, and preparation of potential publications.

References

[1] F. Mazenc and O. Bernard, "Interval observers for linear time-invariant systems with disturbances," *Automatica*, vol. 47, no. 1, pp. 140–147, 2011.

[2] F. Mazenc, T. N. Dinh, and S.-I. Niculescu, "Interval observers for discrete-time systems," *International Journal of Robust and Nonlinear Control*, vol. 24, no. 17, pp. 2867–2890, 2014.

[3] T. N. Dinh and G. Q. B. Tran, "Systematic interval observer design for linear systems," *Automatica*, Vol. 180, pp. 112477, 2025.

[4] D. Efimov and T. Raïssi, "Design of interval observers for uncertain dynamical systems," *Automation and Remote Control*, vol. 77, no. 2, pp. 191–225, 2016.

[5] S.-A. Raka and C. Combastel, "Fault detection based on robust adaptive thresholds: A dynamic interval approach," *Annual Reviews in Control*, vol. 37, no. 1, pp. 119–128, 2013.