Observer Design for Nonlinear Systems - Towards the End of LMI Relaxations

Marouane Alma, Ali Zemouche

1. Background of the thesis

State estimation of dynamical systems is a crucial and important research field for control, diagnosis, and monitoring. Further, the need for nonlinear observers has been felt and pursued in many modern and essential applications, namely self-synchronization in multi-agent systems; consensus achievement in network of systems; cyber-attacks and/or denial of service detection. In the case of nonlinear systems, the problem of state observer design becomes a hard and complicated issue due to the complexity of the structure of nonlinearities of the system in some situations. Well known approaches have been proposed in the literature. For instance, the high-gain observers, the extended Kalman filter, observers designed by solving Linear Matrix Inequalities (LMIs), methods based on nonlinear transformations using the normal forms of observability, and estimation methods based on modulating functions. Despite the several powerful observer design techniques proposed in the recent literature [1]-[8], the problem is far from being definitely solved for general nonlinear systems. Many research tracks remain to be explored to improve current methods. The proposed thesis fits into this context.

2. Objective of the thesis

In this thesis we will work on the development of novel observer design methods for nonlinear systems. The thesis will focus on LMI techniques on which the team is expert. Indeed, after working about more than ten years on this topic, we realized that ALL the LMI techniques existing in the literature fail for particular classes of nonlinear systems, namely systems where all the nonlinearities of the process dynamics or all the output nonlinearities of the system are non-monotonic. A solution has been proposed in [9]-[10] to overcome this obstacle by proposing a switched observer to switches between several regions of monotonicity. This solution is powerful, but it is far from being perfect because of some drawbacks related to the switched rule. To relax more the current LMI-based observer design methods, we have new ideas consisting in considering new observer structures and transforming some nonlinearities of the system. We aim to consider a mathematical feasibility analysis of the LMI conditions by considering the structure of the nonlinearity and its qualitative properties instead of only its quantitative properties as it is usual in the literature. This issue has never been considered in the literature in the LMI framework. The qualitative properties of the nonlinearities will be involved in the LMI conditions, which lead to introduce a kind of "*distance to infeasibility*". This distance can be viewed as a metric to measure the feasibility of the LMIs with respect to the nonlinearity of the system. These theoretical and mathematical issues are motivated by some specific applications in which we have been involved in recent years, namely autonomous and connected vehicles, anaerobic digestion processes, and magnetic sensors. This thesis aims to provide a limit to LMI relaxation methods.

Keywords: Observer design; estimation; nonlinear systems; Lyapunov theory; vehicle dynamics; anaerobic digestion processes.

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Contacts :

Marouane Alma: marouane.alma@univ-lorraine.fr
Ali Zemouche: ali.zemouche@univ-lorraine.fr

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