Doctoral proposal

Thesis: Robust fault diagnosis of cooperative non homogeneous multiagent systems

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Research line: Mechatronic systems

1 Introduction

Cooperative control of multiagent systems has attracted ever-increasing attention in recent years due to the fact that multiple agents can provide much more redundancy than a single agent system. In this scenario, an individual control law for each one of the agents cannot provide a satisfactory performance of the global control task, e.g., distributed cooperative control of microgrids Bidram et al. (2013a,b); Nasirian et al. (2014), cooperative formation control of autonomous underwater vehicles Das et al. (2016), formation control of unmanned aerial vehicles (UAVs) Kuriki and Namerikawa (2014), cooperative control of manipulators Li et al. (2016), to mention a few. Among different topics of MAS, the leader-following, also called cooperative tracking control, has become the most popular consensus problem. In this case, the leader sends information to the agents, then, the controller tries to reduce the error so all follower agents can track the desired trajectory generated by the leader Lewis et al. (2013). The problem of cooperative control for MASs, aiming at designing appropriate distributed control laws and network connection protocols such that the group of agents meets certain coordinated requirements Yang et al. (2020). The works of Ma et al. (2015) and Zhao et al. (2017) present two different approaches for second-order multi-agent systems, one is an optimal strategy and the other is an event-triggered strategy for the communication graph, respectively. Nevertheless, most of the proposed approaches considers linear models, which reduces the method's applicability. In this work, we proposes a convex approach by considering nonlinear models trought Linear Parameter Varying or Takagi-Sugeno models,

Convex models have proven to represent in a better way nonlinear systems with the additional benefit to develop formal stability proofs that guarantee robustness over a broad set of operating conditions López-Estrada et al. (2019). LPV systems can be viewed as polytopic systems composed of linear models blended by scheduling functions. Their main advantage is to extend powerful linear design tools to complex nonlinear models (Shamma, 2012). A literature review about the convex model can be consulted in the recent survey López-Estrada et al. (2019), the books **??** and the references therein. The state estimation and its application to fault diagnosis and fault-tolerant control have gained interest from the theoretical and practical points of view. For example, (Hassanabadi et al., 2017) proposes a fault diagnosis observer with inexact gain scheduling parameters by considering an H_∞ approach. Morato et al. (2019) presents a fault estimation observer that considers an H_2/H_∞ approach and its application to a microgrid system. In Hamdi et al. (2019) was proposed a fault diagnosis for descriptor systems by considering sliding mode to increase robustness. Recently in Gómez-Peñate et al. (2020), the authors propose an actuator multi-integral fault estimation observer based on H_∞ and its application to unmanned aerial vehicles. Previous works show that fault estimation for convex systems is a hot topic and of great interest to the control community. However, only a few papers are reported for multi-agent systems with convex models.

Recently in Tabarisaadi et al. (2019) it was proposed a tracking control with H_∞ performance MAS with convex structures by considering a Takagi-Sugeno model; in this work, 13 agents were controlled to illustrate the controller performance. In Ma and Zhao (2019) the consensus problem was studied for

TS MAS with switching topology. In the work of Fang et al. (2020) was proposed a method for solving the consensus problem of networked LPV MAS with directed long-range interactions. In ur Rehman et al. (2020) was proposed a robust nonlinear adaptive consensus protocol under external perturbations with Lipschitz dynamics; the Lipschitz nonlinearity in the agents' dynamics and the adaptive protocol are reformulated using an LPV approach. For fault diagnosis, there are also fewer works reported; for example, in Chadli et al. (2016) it was proposed a fault diagnosis observer for LPV MAS with sensor fault. This work was extended in the journal version in Chadli et al. (2017) where some numerical examples show the applicability of fault diagnosis observer with LPV formulation. However, it is essential to note that most of the recent works for fault diagnosis and estimation are based on linear models as discussed in our recent work of **?**. This is mainly because the extension of these techniques to LPV is not trivial because the matrices resulting by connecting the observers give some conservatism in the feasibility solution of the resulting linear matrix inequalities. However, this also represents a great opportunity to develop research to guarantee observer convergence and fault estimation.

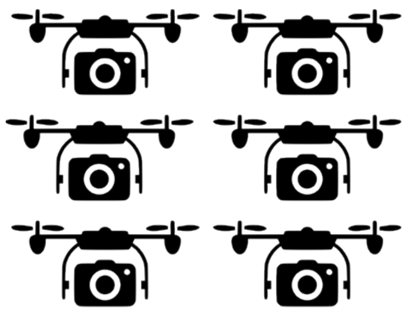
.5 

Figure 1: Homogeneous MAS

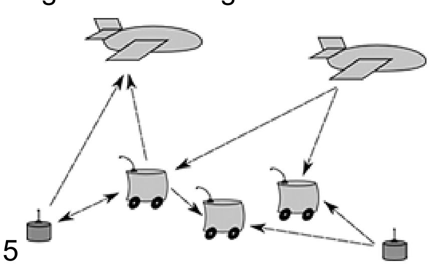
.5 

Figure 2: Nonhomogeneous MAS

In this work, we propose to develop fault estimation observers with convex structures for nonhomogenous multiagent systems. In general, despite that different methodologies are mainly developed for identical agents, there is a difference between agents due to uncertainties or collaboration between other agents. Therefore, nonhomogeneous MAS is more general than homogeneous systems. Also, there are many applications of heterogeneous systems, particularly in collaborative tasks, for example, between a mobile robot and an unmanned aerial vehicle. Only a few works have been reported for nonhomogenous MAS and mainly focussed on linear models (Kim et al., 2010; Zuo et al., 2018; Mondal et al., 2017; Cai et al., 2019). To the best of our knowledge, so far, in terms of convex MAS only homogeneous systems have been discussed. This work will also consider solutions based on linear matrix inequalities to estimate sensor or actuator faults on the agents—the main idea of to increase the safety and reliability of the multiagent system.

2 Background

2.1 Mathematical preliminaries

Consider a graph $\mathcal{G} = (\mathcal{V}, \mathcal{E}, \mathcal{A})$ with a set of N nodes $\mathcal{V} = (v_1, v_2, ..., v_N)$; a set of edges $\mathcal{E} \subset \mathcal{V} \times \mathcal{V}$ that interconnects the nodes in the graph; and, its associated adjacency matrix $\mathcal{A} = [a_{ij}] \in \mathbb{R}^{N \times N}$ whose entries or elements depend on the communication between agents in the graph as it is explained later.

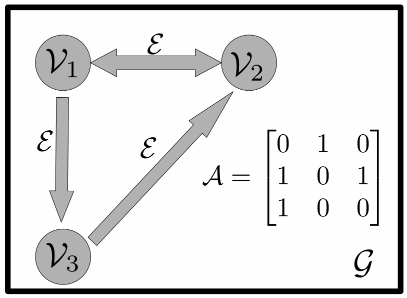


Figure 3: Graph example.

Elements of $\mathcal{E}$ rooted at node j and ended at node i are denoted by (v_j, v_i), which means that information can flow from node j to node i. Elements a_{ij} are the weights of the edge (v_j, v_i), $a_{ij} = 1$ if edge $(v_j, v_i) \in \mathcal{E}$, i.e., exist a connection between agent v_j and the agent v_i, otherwise $a_{ij} = 0$. For example, for a system of 3 agents, the corresponding graph is as in Fig. 3. Undirected graphs consider that $(v_j, v_i) = (v_i, v_j)$, i.e., communication between agents is bidirectional and therefore $a_{ij} = a_{ji}$ with the property $\mathcal{A} = \mathcal{A}^T$, otherwise, it is considered a directed graph or digraph. In this paper, only graphs with a_{ii}=0 are considered. Another important definition is the weighted in-degree of node v_i which expresses the i-th row sum of $\mathcal{A}$:

$$d_i = \sum_{j=1}^{N} a_{ij}; \tag{1}$$

with which $D = diag(d_i)$ is the diagonal in-degree matrix. Finally, let $L = D - \mathcal{A}$ be the Laplacian matrix that includes all the communication information between the agents.

A graph that contains a node that acts like a command generator (leader node) is modeled with an augmented graph $\bar{\mathcal{G}} = (\bar{\mathcal{V}}, \bar{\mathcal{E}}, \bar{\mathcal{A}})$ with a set of $N+1$ nodes $\bar{\mathcal{V}} = (v_0, v_1, ..., v_N)$ and a set of edges $\bar{\mathcal{E}} \subset \bar{V} \times \bar{V}$. Without losing generality, the leader node is labeled as v_0. Then, if there exist a connection between the leader node and the i-th follower nodes, an edge (v_0, v_i) is said to exist with $g_i = 1$ as the weight. These weights are called pinning gains and the diagonal matrix of pinning gains is defined as $G = diag(g_i)$ that represents the connections between the leader node and the i-th agents Lewis et al. (2013). Finally, to express a complete space-state model of all agents the Kronecker product $\otimes$ is used which is defined, given two matrices $A = [a_{ij}]$ and B, as $A \otimes B = [a_{ij}B]$.

2.2 Problem statement and system description

Consider a collection of $N+1$ identical convex multi-agent systems where follower agents dynamical model in continuous time is given by (2):

$$
\begin{aligned}
\dot{x}_i(t) &= \sum_{j=1}^{h} h_j(\xi(t))(A_j x_i(t) + B_j u_i(t)) + H f_i(i) \\
y_i(t) &= Cx(t) + F w_i(i)
\end{aligned}
\tag{2}
$$

where $i = 1, \ldots, N$ and $j = 1, \ldots, h$, $x_i(t) \in \mathbb{R}^n$ is the state vector, $u_i(t) \in \mathbb{R}^m$ is the input vector, $f_i(t) \in \mathbb{R}^r$ is the actuator fault vector, $y_i(t) \in \mathbb{R}^p$ is the output vector and $w_i(t) \in \mathbb{R}^n$ is the sensor noise vector. Matrices A and C are assumed to be observable and H and F are constant and real matrices with appropriated dimensions.

In order to estimate states and faults, the following convex distributed observer could be proposed:

$$
\begin{aligned}
\dot{\hat{x}}_i(t) &= \sum_{j=1}^{h} h_j(\xi(t))\big(A_j \hat{x}_i(t) + B_j u_i(t) - R_j \zeta_i(t)\big) + H\hat{f}_i(t); \\
\hat{y}_i(t) &= C\hat{x}_i(t); \\
\hat{f}_i(t) &= -\Gamma\Phi\left(\zeta_i(t) + \int_{t_f}^{t} \zeta_i(t)dt\right);
\end{aligned}
\tag{3}
$$

where $i = 1, \ldots, N$ and $j = 1, \ldots, h$, $\hat{x}_i(t) \in \mathbb{R}^n$ is the estimated state, $\hat{y}_i(t) \in \mathbb{R}^p$ is the estimated output, $\zeta_i(t) \in \mathbb{R}^q$ is the relative output estimation error of the i-th agent in the communication graph defined later, $R_j \in \mathbb{R}^{n\times q}$ is the observer gain matrix to be designed, and $\hat{f}_i(t)$ is the estimated fault. To deal with fault estimation, a distributed PI fault estimator $\hat{f}_i(t)$ is proposed where the information of relative output estimation error ζ_i is needed. Additionally, the integral term of ζ_i is added to have a faster convergence to the fault. $\Phi \in \mathbb{R}^{r\times p}$ is the fault estimator gain matrix to be designed, and matrix $\Gamma = \Gamma^T > 0$ is the learning rate. Note that t_f indicates the time when the fault occurs.

The observer is developed to estimate states and faults, with this target, state estimation error $e_{x_i}(t)$ and fault estimation error $e_{f_i}(t)$ must to converge asymptotically to zero. Let define the dynamics of the estimation errors:

$$
\dot{e}_{x_i}(t) = \dot{\hat{x}}_i(t) - \dot{x}_i(t) \tag{4}
$$

$$
\dot{e}_{f_i}(t) = \dot{\hat{f}}_i(t) - \dot{f}_i(t) \tag{5}
$$

In addition, if we consider that the agents are not homogeneous, then the local models given in (2) are not identical, which also means that the estimation error computation is not trivial. This problem still open in the literature, in particular for convex representation under faults.

3 Objectives

General

Develop a methodology for designing an active robust fault diagnosis algorithm for multiagent nonhomogenus convex systems subject to partial sensors or actuator faults.

Specifics

- Develop a robust estimation observer for multiagent systems with homogenous topology.
- Develop a fault estimation observer for nonhomogenous systems with linearin order to increase the applicability of the method.
- Test the observer under partial sensor or actuator faults
- In the simulation, apply the proposed methodology to mechatronics systems as a robot mobile and a quadrotor modeled as a double integrator.

4 Goals

- Two papers JCR submitted or accepted in prestigious journals as the Fuzzy Sets and Systems, the International Journal of Control, or Transaction in Automatic Control.
- Three international conference papers as SYSTOL, Safesprocess, World IFAC, CCD, among others.
- 1 Collaboration agreement with the University of Lorraine, France.

5 Timetable of activities

6 Financing

The main goal of this work is to develop theoretical algorithms. Therefore, it is not necessary extra financing for the strengthening of the project. The schollarship will be cover the National Council of Science and Technology (CONACYT) of Mexico.

Act/Sem	I	II	III	IV	V	VI	VII	VIII
Review of the state of the art	X	X	X	X	X	X	X	X
Proposal defense		X						
Develop an homogeneous fault estimation observer			X	X				
Extend to homogeneous observers				X	X			
Pre-doctoral exam						X		
Application to partial actuator or sensor faults						X	X	
Conferences papers		X		X			X	´
Journal papers			X		X			X
Academic stay in Lorraine			X	X	X	X		
Thesis writing								X

7 Collaboration

The work will be done in collaboration with the University of Lorraine. As a result of this collaboration agreement it is expected as a ”cotutelle” student mobility.

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