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Brief paper

Passivation blocks for fault tolerant control of nonlinear systems☆

Iury Bessa [a,b], Vicenç Puig [c], Reinaldo Martínez Palhares [d,*]

[a] Federal University of Minas Gerais, Graduate Program in Electrical Engineering, Belo Horizonte, Brazil
[b] Federal University of Amazonas, Department of Electricity, Manaus, AM, Brazil
[c] Supervision, Safety and Automatic Control Research Center (CS2AC), Institut de Robótica i Informática Industrial (CSIC-UPC), Universitat Politècnica de Catalunya, Barcelona, Spain
[d] Federal University of Minas Gerais, Department of Electronics Engineering, Belo Horizonte, Brazil

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ABSTRACT

This paper describes a novel passivity/dissipativity based approach for fault tolerant control (FTC) of nonlinear systems by means of fault hiding, i.e., by inserting reconfiguration blocks (RBs) between the plant and controller to mitigate the fault effects. The proposed approach is used to design a new kind of RB, called passivation block (PB), which is generically employed for sensor and actuator faults and achieves simultaneously series, feedback and feedfoward passivation of the controller during a fault occurrence. Based on the dissipativity theory, new conditions are obtained to design a dynamic PB (DPB) which requires minimum information on the system model. In particular, the proposed DPB can be systematically obtained by combining the LMI-based conditions based on the knowledge about the passivity indices. Numerical simulations are carried out and indicate that the PBs are able to stabilize an example of a faulty nonlinear system.

1. Introduction

During the last decades, fault tolerant control (FTC) for safety-critical and industrial processes has been extensively studied to improve the reliability and availability of such systems which are subject to sensor and actuator faults, such as offsets and stucks, that degrade the system performance and may lead to instability (Argha, Su, & Celler, 2019; Yang, Jiang, & Zhang, 2012). Therefore, FTC aims to ensure the stability and desirable performance even during the fault occurrence.

In general, FTC techniques can be divided into two groups: passive and active techniques. Passive FTC (PFTC) (Stefanovski, 2018) considers the fault occurrence as a perturbation or uncertainty that must be rejected by the designed controller. In this case, it is not necessary further information on the severity and localization of faults, since the FTC is designed to be robust with respect to them at the expense of performance loss. Otherwise, active FTC (AFTC) (Lan & Patton, 2016) uses the information of a fault detection and isolation (FDI) system to modify the control law aiming to mitigate the fault effects avoiding the unnecessary performance loss in fault-free conditions.

Among the AFTC techniques, the fault hiding stands out due to its ability to maintain the same controller designed for the nominal (fault-free) system during the fault occurrence. Indeed, fault hiding consists in inserting a reconfiguration block (RB) between the faulty plant and the controller that corrects the sensor measurements and translates the control signals by control allocation provided by a controller that does not receive the information about the fault occurrence. Most of fault hiding applications deal with linear systems (Lunze & Steffen, 2006), although there are also applications for linear parameter varying (Quadros, Bessa, Leite, & Palhares, 2020; Rotondo, Cristofaro, & Johansen, 2018), Hammerstein–Wiener (Richter, 2011), piecewise affine (Richter, Heemels, Wouw, & Lunze, 2011), and Takagi–Sugeno fuzzy (Bessa, Puig, & Palhares, 2020; Filasová, Krokavec, & Liščinský, 2016) systems.

Dissipativity and passivity theory is an important paradigm of nonlinear system analysis due to its relation with input–output stability (Khalil, 2000; Kottenstette, McCourt, Xia, Gupta, & Antsaklis, 2014). In particular, the passivity indices (McCourt & Antsaklis, 2010) and passivation techniques (Xia, Antsaklis, Gupta, & Zhu, 2017; Zhu, Xia, & Antsaklis, 2017) are studied to obtain closed-loop systems with desired passivity properties. The dissipativity/passivity framework has been already used to design

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* Corresponding author.
E-mail addresses: iurybessa@ufam.edu.br (I. Bessa), vicenc.puig@upc.edu (V. Puig), rpalhares@ufmg.br (R.M. Palhares).

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