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Actuator Fault Tolerant LQG Control of a Water Delivery Canal*

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***Abstract*— The problem of reconfiguration of the control system to mitigate the effects of actuator faults in a water delivery canal is addressed in this paper. When a fault in an actuator is detected and isolated, the controller is reconfigured by changing the set of manipulated and process variables and using a different controller, associated to a different plant model, in a hybrid systems framework. In order to prevent instability that may be associated with switching among controllers, a dwell time condition is used. Both centralized and distributed LQG controllers are considered. In the case of distributed control, a game approach is followed to coordinate the different local controllers. Experimental results are presented.**

I. Introduction

A. Motivation

Water delivery open canals used for irrigation [1] are large structures whose complexity, together with increasing requirements on reliability and quality of service provides a strong motivation to consider fault tolerant control methods [2]. In order to achieve fault tolerant features, the idea consists in exploring the redundancy in installed sensors and actuators to reconfigure the control system such as to allow the plant operation to continue, perhaps with some graceful degradation, when a sensor or actuator fails. Fault tolerance may be embedded either in centralized multivariable controllers, where a single controller receives the data from all the sensors and uses it to compute the value of all manipulated variables, or in distributed controller networks, where local controllers, each connected to a single gate, negotiate their moves with their neighbors in order to reach a consensus that allows coordinated action among them.

In general, distributed control is useful for water delivery canal since these are plants that may extend over wide areas, with the actuators (gates) separated by long distances, over which data communication systems may be unreliable. The use of distributed control has the advantage of already providing *per se* a certain degree of fault tolerance. If a local controller fails, the others can still ensure their own tasks. However, since the resulting interconnections may yield an unstable overall system, the fault tolerant mechanisms must ensure both a reconfiguration of the communication network and a redesign of the local controllers such as to keep the overall system stable. In [3], [4] a distributed LQG algorithm based on a game approach has been presented and compared to multivariable LQG control. In this paper we extend these algorithms to make them tolerant to faults in actuators.

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B. Literature review

The concept of fault tolerant control (FTC) has been the subject of intense research in the last twenty years [5], [6], [7], in particular in what concerns reconfigurable fault tolerant control systems [8]. This activity yielded a rich bibliography that, of course, cannot be covered here and that comprises aspects such as fault detection and isolation and fault tolerant control design. In relation to distributed control, an important concept is ”integrity”, namely the capacity of the system to continue in operation when some part of it fails [9]. Other type of approach models the failures as disturbances that are estimated and compensated by the controller [10]. In what concerns water delivery canal systems a topic that receives attention due to their immediate economic impact related to water saving is leak detection [11]. Other aspects found in the literature are control loop monitoring [12], and reconfiguration to mitigate fault effects [14], which is the issue considered in this work. Reconfiguring the controller in face of a plant fault falls in the realm of hybrid systems and raises issues related to stability that must be taken into account [13].

C. Contributions and paper structure

The contribution of this paper consists of the application of LQG centralized and distributed fault tolerant control to a water delivery canal in the presence of actuator faults. An algorithm based on controller reconfiguration with a dwell time logic is presented, together with a sufficient condition on the dwell time to ensure stability and experimental results.

The paper is organized as follows: After the introduction in which the work is motivated, a short literature review is made and the main contributions are presented, the canal is described in section II, including a static nonlinearity compensation of the gate model. Centralized LQG control is described in section III and distributed LQG control is described in section IV, whereas actuator fault tolerant control is dwelt with in section V. Experimental results are presented in section VI. Finally, section VII draws conclusions.

II. The Canal System

A. Canal description

The experimental work reported hereafter was performed at the large scale pilot canal of *Núcleo de Hidráulica*

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