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Bicausal bond graphs for supervision: From fault detection and isolation to fault accommodation

A.K. Samantaray*, S.K. Ghoshal

Department of Mechanical Engineering, Indian Institute of Technology, 721302 Kharagpur, India

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Abstract

Model-based fault detection and isolation (FDI) requires an analytical system model from which fault indicators can be derived by assigning proper computational causalities. Many bond graph (BG) model-based techniques for FDI have been developed in recent past. Furthermore, many other advances have been made in the field of control engineering applications of BG modelling. Supervision systems not only perform FDI, but also take the necessary steps for fault accommodation. Fault accommodation is done either through system reconfiguration or through fault tolerant control (FTC). In this paper, it is shown that bicausal BG modelling proves to be a unified approach for sensor placement from the FDI and FTC viewpoint, identification of hardware redundancies for system reconfiguration, generation of fault indicators, estimation of fault parameters for fault accommodation, inversion of systems and actuator sizing for FTC, etc. It is shown that the use of bicausalled BG helps to integrate many of the recently developed advances made in the field of control engineering into development of complex supervision systems.

Keywords: Bond graphs; Bicausality; Analytical redundancy; Fault signature; Fault detection and isolation; Fault tolerant control

1. Introduction

At the 5th international conference on bond graph (BG) modelling, an algorithmic way to derive analytical redundancy relations (ARRs) [1–3] or the so-called constraint structures

*Corresponding author. Tel.: +91 3222 282998/282999; fax: +91 3222 282278.
E-mail addresses: samantaray@lycos.com (A.K. Samantaray), sghoshal@mech.iitkgp.ernet.in (S.K. Ghoshal).

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Nomenclature

Symbol description

T	tank
V	valve
A	cross-sectional area of tank
m	mass of fluid in tank
P	measured fluid pressure
F	measured fluid flow
g	acceleration due to gravity
ρ	density of fluid
Q	mass flow rate of fluid
$\Phi(\,)$ and $\Psi(\,)$	characteristic functions of actuators and controllers
$\phi(\,)$	characteristics of valve, e.g., quick opening, equal percentage, etc.
sign( )	function to correct the direction of flow through a valve
C_{d}	coefficient of discharge of fluid through a valve
$\bar{C}_{\mathrm{d}}$	estimated coefficient of discharge of fluid through a valve
L	measured fluid level in a tank
u	controller command (output)

Subscripts

P	pump (actuator)
PI	proportional-integration controller
1,2	tank and valve numbers

expressed in terms of known system variables, from BG models, was presented [4]. Evaluation of ARRs by using measured data generates the residuals or measures of discrepancies between the actual and the reference system behaviour, which are then used for fault detection. Prof. Peter J. Gawthrop, who was the session chair and champions the use of the concept of bicausality notations [5] in BG models, then remarked and explained that the existing algorithms for ARR derivation could be well represented by using bicausality notations. Nearly 4 years after his observations, we present in this paper a unified approach to fault detection and isolation (FDI) and fault tolerant control (FTC) by using bi-causalled BG models.

Supervision systems mainly perform two tasks: FDI and decision making to recover from the fault. Supervision systems utilize a set of tools and methods to operate a process in normal situation as well as in the presence of failures or undesired disturbances. The presence of a fault is detected at the monitoring level, which determines whether the process is in normal operation or not and the tools associated with diagnosis are executed after detection of abnormal process state. Fault accommodation is performed in situations where parameters or constraint structures change due to a fault [1].

Fault accommodation is performed through FTC and/or system reconfiguration. In FTC, the objective is to control the system under actual constraints. In system reconfiguration, part of the actual faulty system is replaced by another one, e.g. selection