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Functional Hybrid Bond Graph for Operating Mode Management

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Abstract: This paper proposes the Operating Modes Management (OMM) of the Hybrid Dynamical Systems (HDS) using a generic tool named Hybrid Bond Graph (HBG) driven by an automaton. This tool is used for modeling and for fault detection and isolation (FDI) as well. The innovative interest is the use of only one tool (the HBG) for the behavioral and functional modeling and the OMM taking into account the FDI results. A hybrid hydraulic example is presented to demonstrate the effectiveness of this technique.

Keywords: Supervision, Diagnosis, Operating Mode management, Hybrid Bond Graph, Functional Model.

1. INTRODUCTION

Control systems are expected to achieve different objectives or missions at different times. Missions are organized into coherent subsets named operating modes (OM) and at a given time only the missions belonging to the current OM have to be fulfilled. The achievement of these current objectives relies on the services provided by the system components (e.g, sensors, actuators, process components). Connecting and disconnecting a component, by switching from an OM to another, makes the system a Hybrid Dynamical System (HDS). Such system's dynamic evolves in both ways: continuous and discrete. Discrete dynamic is expressed by boolean firing expressions which defined the conditions to switch between the different OM. Inside the current mode, the dynamic evolves continuously with respect to a given set of equations, see Alur et al. (1995), Lygeros et al. (2003). Several approaches exist to represent the behavior of such systems, for examples, hydrid automaton, hybrid bond graph and hybrid petri net, Bertrand et al. (2015), Mosterman and Biswas (1995), Ghomri and Hassane (2015). The realization of the system objectives can be compromised if a component fails. This is the reason why, in order to increase the system safety and reliability, control systems must integrate Fault Detection and Isolation (FDI) and Fault-Tolerant Control (FTC) procedures. As a result, the selection of the current OM is not only determined according to the user objectives but also according to the operational availability of the system components.

In this paper, the Hybrid Bond Graph (HBG) driven by an automaton is proposed to represent, and manage online, the different OM of a HDS. The HBG is defined as a BG with controlled junctions representing the behavior of controlled switches, Mosterman and Biswas (1995).The HBG represents through the controlled junctions, the distinct system configurations while the automaton determines the value of the discrete signal sent to each controlled junction. The availability of the different components is obtained through an online hybrid BG diagnoser which is developed to directly generates fault indicators (named residuals) without any analytic explicit calculation of redundancy relations.

The paper contains six sections. In section II the event driven hybrid bond graph is detailed, Section III shows the use of the event driven hybrid bond graph for FDI. The OM management is detailed in section IV and then illustrated on a simple hydraulic system in section V. Finally, section VI is preserved for the conclusion.

2. EVENT DRIVEN HYBRID BOND GRAPH

Definition 2.1. (BG). A Bond Graph is an static oriented graph $BG(E, A, J)$ where

- $E = \{S_e\} \cup \{S_f\} \cup \{R\} \cup \{I\} \cup \{C\} \cup \{TF\} \cup \{GY\} \cup \{D_e\} \cup \{D_f\}$ is the set of elements representing fundamental energetic processes. S_e and S_f are, respectively, effort and flow source elements. They provide energy which is dissipated by the resistive (R), or stored by the capacitive (C) and the inertia (I) elements. TF and GY are TransFormer and GYrator used to represent energy transformations from one domain to another. D_e and D_f are effort and flow detectors associated with measurement functions.
- A is the set of the oriented bonds representing the power exchange between the elements $el \in E \cup J$. They are associated with two conjugated variables: the effort e (above the bond) and the flow f (below the bond). Effort is the intensive variable (e.g. pressure, force, voltage) and flow is the derivative of the extensive variable (e.g. volume flow, velocity, current). The power exchanges (energy variation) are determined through the so-called relation $P = e.f$.

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The positive direction of the power flow is represented by the half-arrow on the bond (see: Fig. 1).

- J is the set of multiport-junctions used to connect elements of E by a 0-junction when the effort is the common variable and by a 1-junction when the flow variable is the same.

Definition 2.2. (Controlled Junction). A controlled junction is a dynamical junction associated to a boolean control signal. The controlled junction behaves like classic junction if it receives the ON control signal (effort value (resp. flow value) associated with all connected bonds are equal and sum of the flow values (resp. effort values) is equal to 0 for a 0-junction (resp. 1-junction)). The OFF control signal sent to a 0-controlled junction (resp. 1-controlled junction) forces the effort (resp. flow) value at all connected bonds to 0, expressing that there is no energy transfer across the junction, see Mosterman and Biswas (1995).

Let n be the number of the controlled junctions used to represent the dynamical behavior of a switching system. Let $\beta_i = [sw_{i1}, sw_{i2}, ...sw_{in}]$ be the vector representing, at a given time, the state i of the n junctions sw_j. Let S be the set of 2^n possible vectors β_i. Let B be a set of bond graphs BG_i. The HBG can then be defined as follow.

Definition 2.3. (HBG). A Hybrid Bond Graph is a bijective map:

$$\begin{aligned} HBG: \quad S &\longrightarrow B \\ \beta_i &\longmapsto BG_i \end{aligned}$$

Fig. 1 gives an example of the two BG generated from a controlled junction. They correspond to a same HBG.

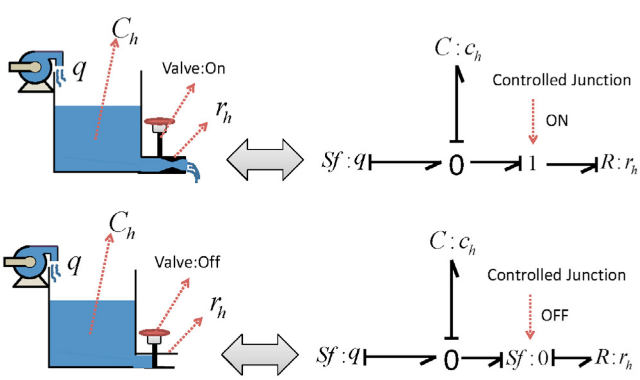

Fig. 1. HBG with controlled junction.

The HBG appears as a very powerful tool to represent the different OM of an HDS. To each OM corresponds a specific behavior which can be describe by a subgraph HBG_j of the global HDG. This subgraph $HBG_j \subseteq HBG$ allows to achieve the missions associated to the mode OM_j. It groups the bond graphs $\{BG_i, i \in [1, n]\}$ which will be sequentially activated through the reception of the corresponding control junction vectors $\{\beta_i, i \in [1, n]\}$, in the same way, the instructions of a software application are sequentially run.

Transitions from one OM_j to another one are controlled by an automaton and are based on predefined conditions named guard conditions. Events such as modification of a characteristic physical value of the system, modification of the user objectives, detected faults or time periods are taken into account in the specification of the guard conditions. These guards allow to evaluate the possibility to stay in the current mode or to switch to another one. According to the selected OM, appropriate subgraph $HBG_j \subseteq HBG$ is selected. Through the BG it groups, it is used to control and diagnose the real system, in real time (see Fig. 2). Indeed, each BG_i, moreover to be used as simulation model, is used as reference model by the diagnoser to analyze the consistence between the predicted values and the real values of the measured variables. More formally, the Event Driven Hybrid Bond Graph is defined as follow.

Definition 2.4. (EDHBG). An Event Driven Hybrid Bond Graph is an automaton

$$\begin{aligned} HA &= (HBG(.), Q, Init, D, E, G) \\ &= (HBG(.), H_s) \end{aligned}$$

where the HBG is used to represent the set of the distinct system configurations, while the simple automaton $H_s = (Q, Init, D, E, G)$ is used to represent the transition conditions from one configuration to another one. $Q, Init, D, E$, and G are respectively the sets of the discrete states, the initial conditions, the mode domains, the transition arcs and the guard conditions, Lygeros et al. (2003).

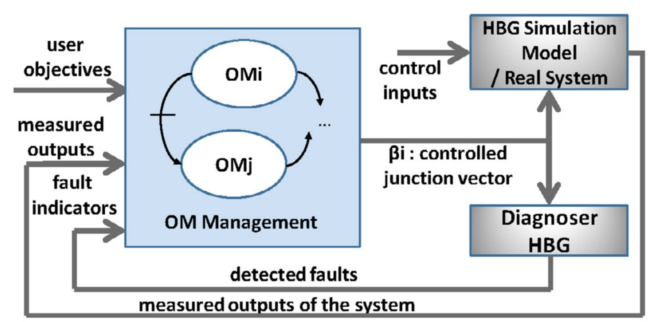

Fig. 2. Event Driven Hybrid Bond Graph

3. FDI ONLINE DIAGNOSIS

The achievement of system missions rests on the services provided by the system components and can be compromised if some components fail. The structural and causal properties of the BG can be used to implement fault detection and isolation procedures allowing to evaluate service availability, Bouamama et al. (2005). To each service corresponds a BG element or a set of BG elements, refer for example to Fig. 1 to see how the two services provided by a On/Off valve are represented. The diagnoser uses the adequate reference BG model directly obtained from HBG model using the controlled junctions vector β_i showed in definition 2.3. A derivative causality is assigned to this model and sensor elements D_f, D_e are respectively dualized into sources of flow (S_f) and effort (S_e). The sources receive as input values, the corresponding measures directly obtained from the real process. The diagnoser uses then these values to check the junction energy laws without requiring an explicit calculation of the analytic redundancy relations. The process is illustrated by Fig. 3. The first part of the figure shows the dualization of