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Mode Recognition of Hybrid Dynamical System a Bond Graph Approach

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Abstract: In this paper, we develop a methodology to identify the current mode of Hybrid Dynamical System (HDS) based on Bond Graph (BG) approach. The technique is also able to detect and to isolate the continuous and discrete faults affected the system. Analytical Redundancy Relations (ARR) based methods are used to generate the fault indicators namely residuals for the identification of the current mode. An illustrative example shows the efficiencies of the proposed approach.

Keywords: Hybrid System, Identification, Mode, Residuals, ARR.

1. Introduction

Hybrid Dynamical Systems (HDS) are systems which continuous and discrete subsystems are continuously in interaction [1][2]. These systems exist in many fields such as electric, mechanic, hydraulic…. Recently, there are intensive study concerned the HDS in the model design, control strategy and diagnosis [3][4][5]. Among the works appeared in the hybrid modelling by BG, we cite [6][7]. The problems investigated are the analysis and the diagnosis systems. In this paper, we propose an approach to recognize the current mode from the residuals generated by ARR.

The paper is organized as follows: in section 2, we present the HDS modeling based on BG approach. Then the recognition mode of HDS is investigated in section 3. The section 4 proposes an illustrative example which develop the considered technique. Finally, simulations results and conclusion remarks are presented.

2. HDS based BG modeling

The HDS scheme is presented in fig.1. It shows the interaction between the continuous and the discrete part of the HDS. In this work, the continuous subsystem is modeled by BG approach and the discrete part is described by a finite state automata which indicated the mode evolution in the HDS.

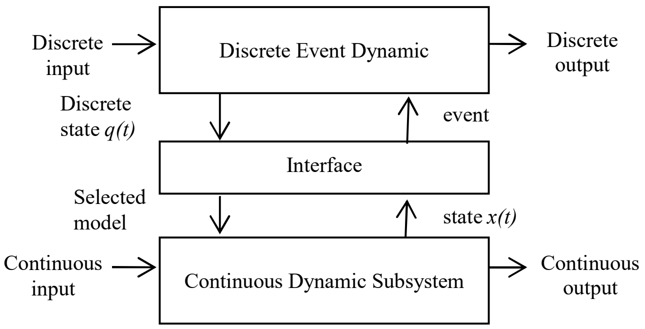

Figure 1. HDS structure

2.1. BG Modelling

The BG is a powerful tool for physical systems modeling. It created by M. Paynter in 1959 [8] and then developed by [9]. The formalism supports model structure analysis and provides a good framework for compositional modelling approaches. The BG approach has been proven effective for the modelling and simulation of HDS.

2.2. Finite State Automata

The finite state automata (FSA) is a discrete event model which is described by finite set of discrete states $Q = \{qi \; ; \; i \in M\}$ with M represents the possible modes qi of the system and set of forced σ^f (controlled) and spontaneous σs transition (switching) of state. The controlled transition is an external event of the HDS that is specified by the operator or the control algorithm.

2.3. Hybrid modeling

In this paper, we propose to combine BG modeling to FSA representation. The modeling approach structure is presented in fig 2.

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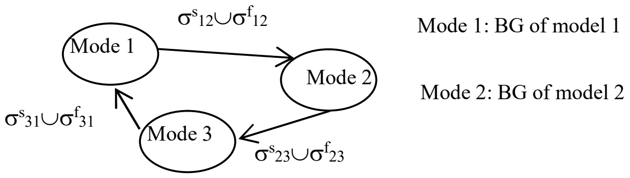

Figure 2 .BG-FSA for HDS modeling

The combined model offers some advantages such as both continuous and discrete behaviors of HDS are described by specific tools and also due to their graphical representation, the hybrid model is very clear.

3. Mode Recognition and FDI

The identification mode is based on residuals (see Fig 3.) generated by parity space or observers approaches. When the system evolves in its mode, the residual is assumed to be equal to zero, in the normal evolution (safety mode) and no disturbances affected the systems. The FDI techniques of HDS concern the diagnosis of the continuous or the discrete part of the HDS. The continuous faults include the sensors and actuators faults. The discrete faults concern the no transition mode, the forced transition and the switching to non successor mode. In this paper, the structured residuals deduced from ARR will be used to identify the active mode of HDS and to estimate the switching time.

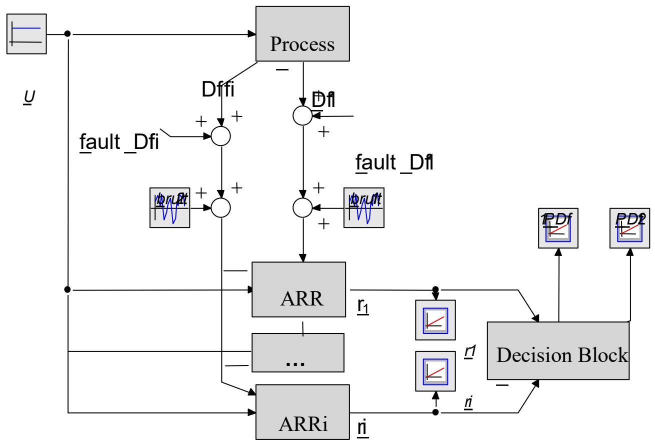

Figure 3. Mode Recognition and FDI by ARR

The active mode identification without fault is obtained by the binary signatures Sri of ARR such as:

- If $r_i = 0$ then $S_{ri} = 0$
- If $r_i \neq 0$ then $S_{ri} = 1$

4. Illustrative Example

The developed technique is implemented on the hydraulic process considered in Aouadi [10]. It consists of a pool added to a storage tank of water considered for irrigation. The role of the system is to keep the level water in the pool between h_{1min} and h_{1max}. Any volume added by the external environment over h_{1max} will be stored in the tank (open the valve EV_{12}) if it is not full, otherwise it drains out of the pool by opening the valve EV_1 as shown in Fig.4.

The water levels are measured by discrete sensors L_1 and L_2. The bond graph model of the system is presented by fig 5. The elements C_1 and $C_2$are respectively the capacity of the water storage in the pool and the tank. The hydraulic restriction R_i models the losses in the pipes.

The valves EV_i are described by modulated transformers (MTF_i) controlled with a logic signal k_i. External environment is modeled by a flow source modulated by a signal "env". The water levels in the pool and the tank are provided by efforts sensors De_1 and De_2 such as:

$$V_{pool} = C_1\, De_1 \Rightarrow h_1 = \frac{1}{S_1} C_1 De_1$$

$$V_{Reservoir} = C_2\, De_2 \Rightarrow h_2 = \frac{1}{S_2} C_2 De_2$$

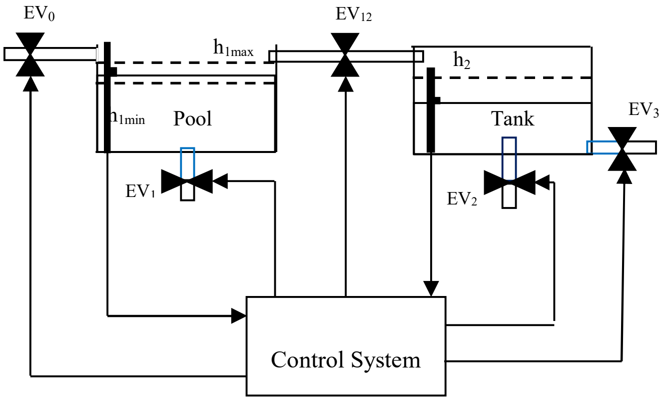

Figure 4. Hydraulic Process of pool system with water storage tank

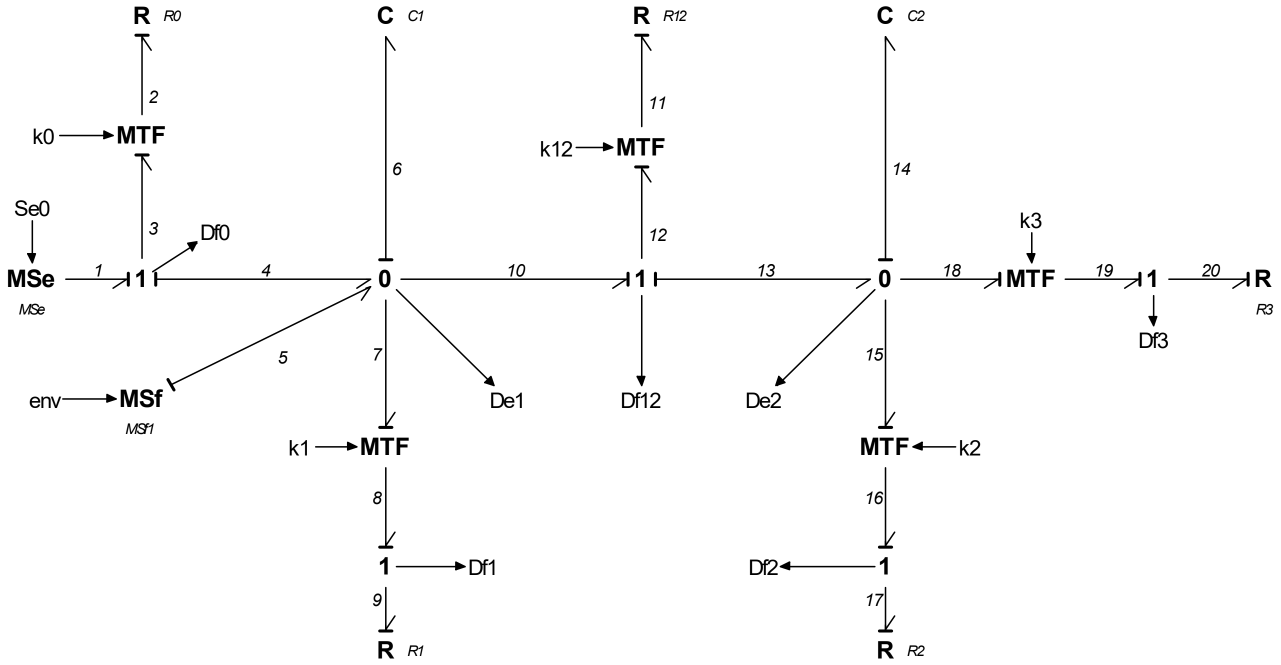

Figure 5. BG model of the hydraulic process in all modes

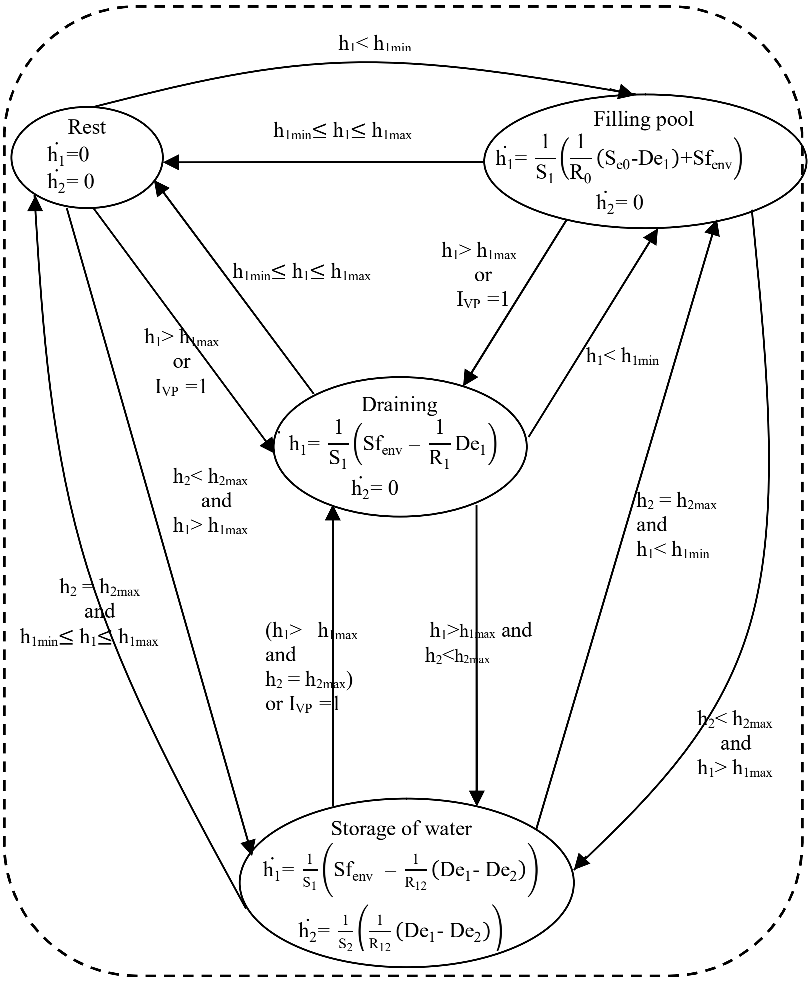

Figure 6. Hybrid automaton of pool system with water storage tank

We consider four healthy mode operating for the study system (Table 1).

Table 1. Modes operations of the pool process

Mode	k_0	k_1	k_{12}
0 : Rest	0	0	0
1: Draining	0	1	0
2: Filling pool	1	0	0
3 : Storage of water	0	0	1

The switching between modes is presented by the hybrid automaton of fig 6. Each mode is described by its BG model as shown in Fig. 7.

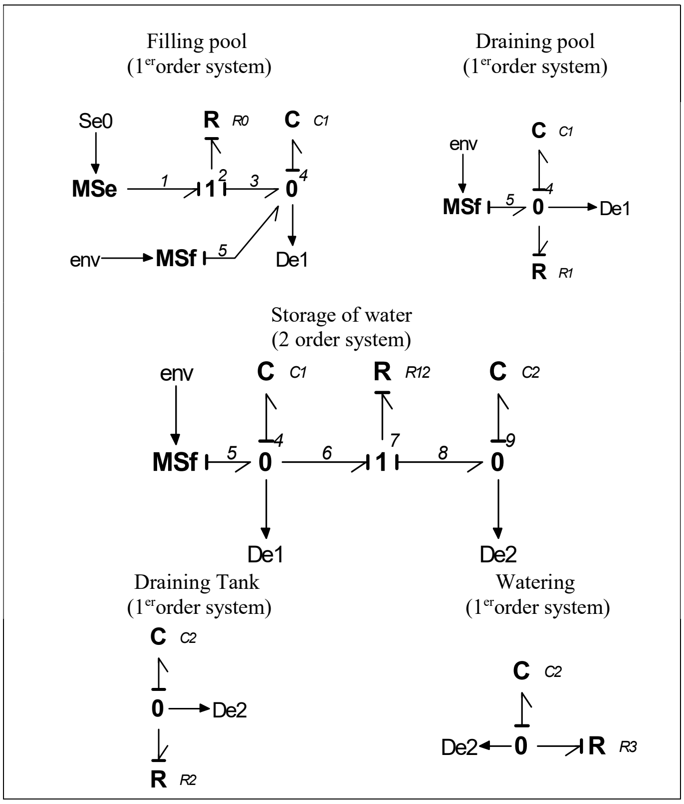

Figure 7. BG models of each mode of pool system with water storage tank

From structural and constitutive laws deducted from the bond graph models of Fig.7, the structured residuals (ARR) of the system are generated:

Residual r_1 associated to the filling pool mode (k_0=1 and k_i=0):

$$r_1=\frac{(Se_0-De_1)}{R_0}+env-C_1\dot{De}_1=0$$

Residual r_2 associated to the draining pool mode (k_1=1 and k_i=0):

$$r_2=De_1-R_1Df_1=0$$

Residual r_3 associated to the storage of water mode (k_{12}=1 and k_i=0):

$$r_3=(De_1-De_2)-R_{12}Df_{12}=0$$

Residual r_4 associated to the watering mode (k_3=1 and k_i=0):

$$r_4=De_2-R_3Df_3=0$$

Residual r_5 associated to the draining Tank (k_2=1 and k_i=0):

$$r_5=De_2-R_2Df_2=0$$

The discrete mode evolution ($\hat{q}$) and the residuals for each operating mode are described by fig 8.

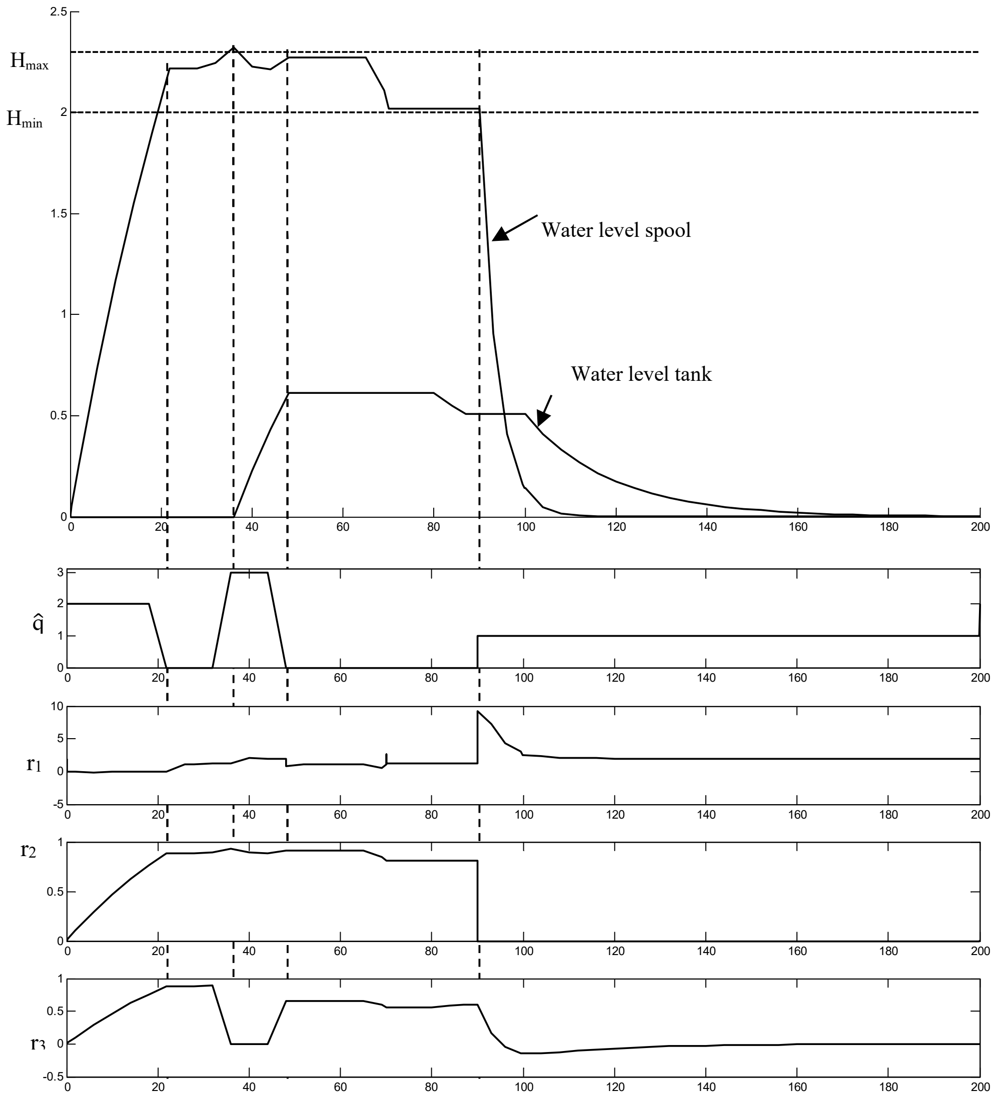

Figure 8. Temporal evolution of residuals and estimated modes

The current mode (q) is identified by the recognition mode scheme based on the residuals (ARR). To better identify the discrete active state, the residuals (ARR) must not be similar. Each residual r_i must be zero when the system evolves in its mode and if there is no fault affected the system. The problem of modes similarities is often known by non discernability modes.

In our work, the residuals ri are equaled to zero in different time intervals so the problem of similarity between modes is not present.

The rest state is identified when all residuals ARR (r_1, r_2, r_3) are non-zero.

The different modes are described in Table 2.

Table 2. Recognition modes by binary signatures deduced from ARR

Time(s)	**ARR**			**Curent Mode**
	S_{r1}	S_{r2}	S_{r3}	
$0 \leq t \leq 21.96$	1	0	1	Mode 2 : Filling pool
$21.96 \leq t \leq 36$	1	1	1	Mode 0 : Rest
$36 \leq t \leq 48$	1	1	0	Mode 3: Storage of water
$48 \leq t \leq 90$	1	1	1	Mode 0: Rest
$90 \leq t \leq 200$	0	1	1	Mode 1: Draining pool

5. Conclusion

In this paper, a hybrid dynamic BG based modeling is proposed to identify the current mode and to estimate the switching time of HDS. The mode recognition is based on the structured residuals generated from ARR technique. The simulation results show the efficiencies of the proposed method. The future work will be focused on the development of a Fault Tolerant Control (FTC) for HDS to insure the system operation.

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