



Fault Diagnosis in Discrete Event Systems using Multi-model Approach

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Abstract—Seeing that the discrete event systems can generate undesirable sequences, several authors focused on the problem of diagnosis. However, few considered the management operating mode in an uncertain environment. In this context, we propose an approach allowing the diagnosis of unobservable events, taking into account the different operating modes in a physical system. Our approach is based on multi-model approach; where each model describes a system in a given operating mode. We will present, in this paper, architecture to ensure the diagnosis of multi-model system. For this, we propose an algorithm to resolve the ambiguity problem and to ensure the commutation between different operating modes where several failures can occur.

Keywords— discrete event system, operating mode management, multi-model, diagnosis.

I. INTRODUCTION

Mode management is one of control design problems in discrete events systems. In this context, several works [1], [2], [3] focuses on the conception models representing a behavior modal of a complex system. We interest in this article in the multi-model approach [2], [4] which involve representing a complex system by a set of simple models. Each model describes the system in a given operating mode and where several failures can occur. This approach supposes that the system can be engaged only in one operating mode at a time. The commutation between these operating modes takes place when a particular event called commutation events occurs. Thus, the activation and inactivation of an operating mode is carried by the occurrence of a commutation event. These events allow switching from the mode which the system performs perfectly its task, known as nominal mode, to a mode for continuous a task in despite a failure, known as degraded mode. Thus, the occurrence of failure event leads to the alternation of the nominal mode to a degraded mode, and the occurrence of the repair event implies the return of the system in the nominal mode. While all existing works on modal decomposition [3], [5], [6] suppose that the commutation events are observable. This is the starting point of our work for which we consider that the failure and repair events, which take place during the alternation of the operating modes, are unobservable events. For this, we propose the diagnosis multi-model architecture in order to manage perfectly the different operating modes and to ensure their switching in the presence of the failure events. To cure the ambiguity problem between local diagnosis in each mode, we use a coordinator based on proposal algorithm. This paper presents the first work of a multi-model approach to realize the fault diagnosis in DES.

The paper is organized as follows: Section 2 introduces briefly the multi-model approach. In section 3, we present the concept of our approach for multi-model diagnosis and the proposed algorithm to resolve the ambiguity problem applying to illustrative example. Study conclusions are presented in section 4.

II. OPERATING MODE MANAGEMENT

A. Definition of operating mode

The multi-model concept involves representing a complex system by a set of simple models, each of which describes the system in a given operating mode. We consider two type of operating mode: nominal mode and degraded mode. A physical system involves a set of nominal and degraded modes. Indeed, each system admits that only one mode of normal functioning (nominal mode); by contrast, it can have several failure modes (degraded mode). In this approach, the nominal mode will always be considered the first selected mode.

Definition 1:

Let $I = \{1, 2, \dots, n\}$ a set of operating modes, where $n \in \mathbb{N}$ and $n \geq 2$. For each operating mode $i \in I$, we associate to an automata model $G_i = (Q_i, \Sigma_i, \delta_i, q_{i,0}, Q_{i,m})$ where:

- Q_i : is the set of states of mode i ,
- Σ_i : is the alphabet of symbols,
- $\delta_i: Q_i \times \Sigma_i \rightarrow Q_i$ is the partial transition function.
- $q_{i,0}$ is the initial state in the mode i ,
- $Q_{i,m} \subseteq Q_i$ is the subset of marker states.

For any state $q \in Q_i$ and any event $\sigma \in \Sigma_i$, we write $\delta_i(q, \sigma)!$ (resp. $\delta_i(q, \sigma) \rightarrow!$) $\delta_i(q, \sigma)!$ if $\delta_i(q, \sigma)$ is defined (resp. isn't defined). This function can be extended as follows: $\delta_i: Q_i \times \Sigma_i^* \rightarrow Q_i$ such $\forall s \in \Sigma_i^*$ and $\forall \sigma \in \Sigma_i$, $\delta_i(q, s\sigma) = \delta_i(\delta_i(q, s), \sigma)$ and $\forall q \in Q_i, \delta_i(q, \varepsilon) = q$;

The set Σ_i^* contains all possible finite strings (i.e., sequence) over Σ_i and the null string ε . The language generated by G_i ,

denoted by $L(G_i)$, is also called the closed behavior of G_i : $L(G_i) := \{s \in \Sigma_i^*, \delta_i(q_{i,0}, s)!\}$.

The global set of events Σ_{global} of a system is given by the union of all alphabets Σ_i of elementary automata models G_i increasing by the set of commutation events Σ_c . Furthermore, the set of commutation events is disjoint of the different set of models: $\Sigma_c \cap \Sigma_i = \emptyset$ (for $i \in I$). Although, $\Sigma_i \cap \Sigma_j$ can't empty (common components between modes).

B. Commutation between different models

Considering several operating modes, we define n operating modes and m possible commutations. The set Σ_c of commutation events is defined as $\cup_{i,j,i \neq j}^n \{\alpha_{i,j}\}$ where $\alpha_{i,j}$ presents the event ensuring the switching between mode i to mode j (with $i \neq j$). This event can appear as fault event or as repair event. For a given commutation, we specify that for a given mode several switching events can be considered. Moreover, from mode i another commutation event $\alpha_{i,k}$ can lead to mode k . This commutation mechanism is illustrated by Fig.1.

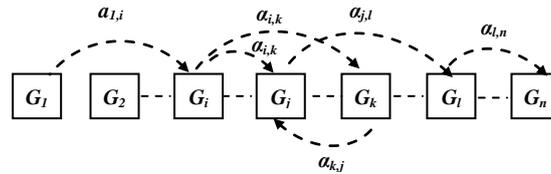


Fig. 1 Commutation between different model modes

Definition 2:

Let C a partial function defining the possible commutation between different operating modes. $C(i \rightarrow j)$ is true if and only if there exists a commutation from the mode i to mode j .

III. MULTI-MODEL DIAGNOSIS

The fault diagnosis methods using in industrial are varied. Their general principle is based on a comparison between observations during the functioning of the system on normal behavior and failure behavior. There are various structures of decision depending on distribution of the available information on the process [7], [8], [9]. There provides the best performance in terms of diagnosis, but leads to combinatorial explosion and to ambiguity problem. We propose to solve this issue by using the multi-model approach and to create the new diagnosis architecture of large discrete event systems.

The multi-model concept involves representing a complex system by a set of simple models, each of which describes the system in a given operating mode. Problems such as alternation and model tracking must therefore be studied in the presence of the failure events (unobservable events). In fact, the system is assumed to operate in a single mode, represented by its model G_i . When a failure or repair event (a so-called commutation event in our context) occurs, the system will switch to another operating mode represented by its model G_j . In this case, G_j must be directed to a starting state in the presence of the failure event. For this, we propose an approach to diagnose the multi-model systems and to cure the commutation problem between the different models. Furthermore, we present the multi-model diagnosis architecture as illustrated in Fig.2.

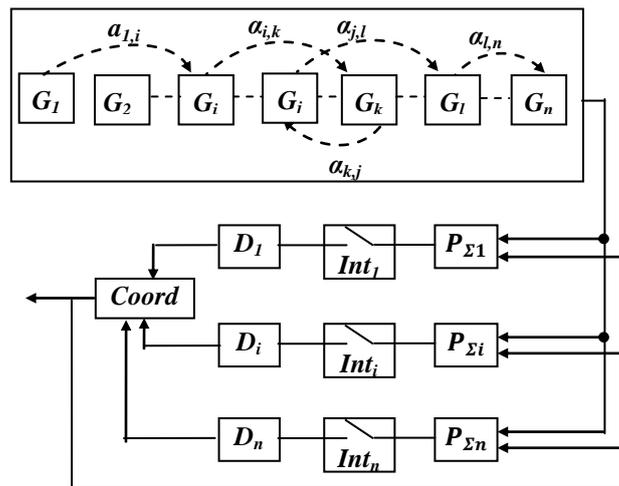


Fig. 2 Architecture of multi-model diagnosis

Considering n operating modes, we define $\Sigma_{i,0}$ the set of observable events in the mode $i \in I$, with $I = \{1,2, \dots, n\}$. The block P_{Σ_i} , in the Fig.2, represents projection of possible trace in the set Σ_{global}^* on the set $\Sigma_{i,0}^*$ to delete the unobservable events in mode i . We define an interrupter Int_i which allows or disallows of passage information to activate the diagnoser associated to each operating mode i . The associate diagnoser for each mode i , as shown by the block D_i , will make a decision depends on type of current mode (nominal or degraded). Each diagnoser sends its local decision to a coordinator which will manage between the different diagnosers and identify the current mode with its final decision. In our approach,

the coordinator respects the rules activation with memory to fuse all transmitted local decisions of existing diagnosers. Each block in our proposal multi-model diagnosis architecture is defined as follows:

Definition 3:

The projection function P_{Σ_i} allows to observe the occurrence of events in alphabet Σ_i . This function is given as follows:

$$P_{\Sigma_i} : \Sigma_{global} \rightarrow \{0, 1\}$$

$$P_{\Sigma_i}(\sigma) = \begin{cases} 1 & \text{if } \sigma \in \Sigma_i \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Definition 4:

Let Int_i be the interrupter which allows or disallows of passage information, which is define as follows:

$$int_i = \begin{cases} 1 & \text{if } P_{\Sigma_i}(\sigma) = 1 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Definition 5:

Let D_i be the active diagnoser when the current interrupter is true $Int_i = 1$. Each diagnoser takes the decision no fault "NF" when the current mode i is the nominal mode, fault "F" for degraded mode otherwise no decision "ND".

$$D_i : \Sigma_{global} \rightarrow \{NF, F, ND\}$$

$$P_{\Sigma_i}(\sigma) = \begin{cases} NF & \text{if } int_i = 1 \text{ and } i \text{ is nominal mode} \\ F & \text{if } int_i = 1 \text{ and } i \text{ is degraded mode} \\ ND & \text{if } int_i = 0 \end{cases} \quad (3)$$

In the case where there are several fault events to diagnose in the activation sequence S_a , we use the terminology fault F_i to indicate the presence of the event f_i in a trace S_a .

By convention, we assume that the initial active mode M_a is nominal mode n . For each event, we determine the local diagnosis decision in each mode i . If there is a decision which differs to ND then depending on the inactive mode, the coordinator makes a decision for the current mode. To ensure the monitoring mechanism, the coordinator treats all possible commutations using the function C . The rule of the coordinator is to determine the active mode in the presence of fault taking into account the possible commutation from the inactive mode. To facilitate the treatment of the coordinator, we propose the following algorithm.

Definition 6:

In our multi-model diagnosis architecture, we associate to coordinator the result as follow:

$Coord = (M_{ina}, M_a, D_{M_a}(\sigma))$ where M_{ina} the inactive mode, M_a , the active mode and $D_{M_a}(\sigma)$ the diagnosis decision of active mode when the event σ occurs. This event σ belongs to the projection observable of activation sequence S_a , with $S_a \in L(G_{global})$.

Algorithm: Treatment of $Coord$ in multi-model diagnosis architecture

Require: S_a, I

Ensure: $Coord$

Initially $M_a = n$ /* M_a active mode */

for each event $\sigma \in S_a$

for each operating mode $i \in I$

if $D_i(\sigma) \in \{NF, F\}$ then

if $i \in M_a$ or $\sigma \in \Sigma_{M_a} \cap \Sigma_i$ the $Coord = (M_a, M_a, D_{M_a}(\sigma))$

elseif $C(M_a, i) = 1$ then

$Coord = (M_a, i, D_i(\sigma));$

$M_a = i$

endif

endif

endif

endfor

endfor

Return $Coord$

IV. APPLICATION

The proposed approach is illustrated by means of a production example in Fig.3. This system comprises four machines $M1, M2, M3, M4$ and by one buffer B. The machines are used to process a part and the buffer is used as storage between

the machines with a maximal capacity of 1.

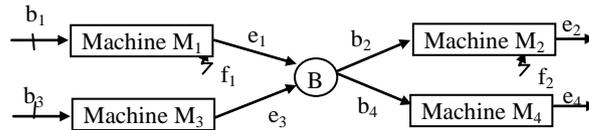


Fig. 3 Production system with four machines and intermediate stock.

In this system, each machine M_i is a resource used to respond to a task defined by the designer. The machines operate independently, where M_i picks up a work piece from an infinite being (modeled by event b_i) and places it in buffer after completing its function (symbolized by the occurrence of event e_i). The shutdown state of machine M_i is labeled by the activity A_i and the running state by the activity M_i . P_1 (resp. P_2) represents a state where the machine M_1 (resp. M_2) is broken due to malfunction and modeled by the event f_1 (resp. f_2). Repair of machine M_1 (resp. M_2) is modeling by the event r_1 (resp. r_2). The automaton modeling machines M_1 and M_2 (resp. M_3 and M_4) are denoted G_1 and G_2 (resp. G_3 and G_4), as shown in Fig.4(a) (resp. Fig.4(b)). The dotted arrows represent the commutation events.

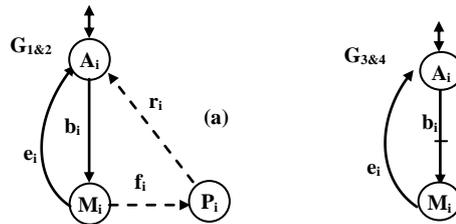


Fig. 4 (a) Automata model G_i of machines M_1 and M_2 (b) Automata models G_i of machines M_3 and M_4

The system has four operating modes, such as $I = \{n, d1, d2, d3\}$. Fig. 4 represents the switching behavior between these modes, where G_i is the automaton model of the mode $i \in I$. The first one, which is the initial mode, is the nominal mode n . The other modes are the degraded modes $d1$, $d2$ and $d3$ which, respectively, depend on whether the machine M_1 , M_2 or M_1 and M_2 will fail. In the case of malfunction, the machine M_1 is replaced by the machine M_3 and the machine M_2 by the machine M_4 . The malfunction of machine M_1 (resp. M_2) is modeled with the commutation event f_1 (resp. f_2) while the repairing is modeled with the commutation event r_1 (resp. r_2). These commutation events $\Sigma_c = \{f_1, r_1, f_2, r_2\}$ don't appear in these models. Indeed, these events will be considered for the passage from a mode to the other.

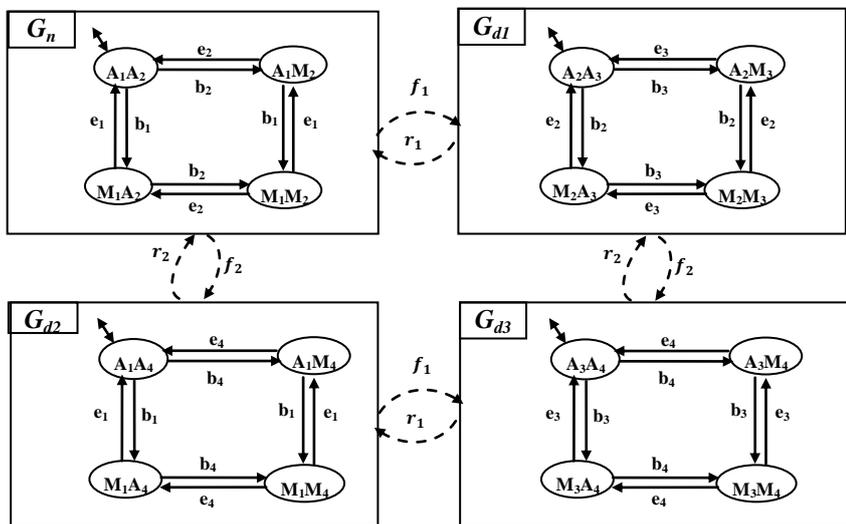


Fig. 5 Different possible commutations

In this example, the set of events Σ_{global} can be partitioned into four sets: $\Sigma_n = \{b_1, e_1, b_2, e_2\}$ alphabet of nominal mode n , $\Sigma_{d1} = \{b_2, e_2, b_3, e_3\}$ alphabet of degraded mode $d1$, $\Sigma_{d2} = \{b_1, e_1, b_4, e_4\}$ alphabet of degraded mode $d2$, $\Sigma_{d3} = \{b_3, e_3, b_4, e_4\}$ alphabet of degraded mode $d3$ and $\Sigma_c = \{f_1, r_1, f_2, r_2\}$ commutation events. The events of the latter alphabet Σ_c are unobservable events.

By hypothesis, the occurrence of failure event f_1 (resp. f_2) of machine M_1 (resp. M_2) can take place from states in the nominal mode or the degraded mode $d2$ (resp. $d1$) where the machines M_1 (resp. M_2) is in normal operation. Before continuing, we assume, henceforth, that the event return r_1 (resp. r_2) can occur only from states in the degraded mode $d1$ (resp. $d2$) or $d3$ when the machine M_3 (resp. M_4) has finished its task.

We consider an example of the activation sequence $S_a = b_1 b_2 f_1 b_3 e_3 f_2 b_4 e_4 r_1 b_1 r_2 b_2$. In proposal approach assumes

that the commutation events are unobservable. Thus, our system trait only the observable projection of activation sequence $S_{a,o} = b_1b_2b_3e_3b_4e_4b_1b_2$. We apply our approach architecture (see Figure. 2) for multi-model system to detect unobservable events. The associate diagnoser for each mode $i \in \{n, d1, d2, d3\}$ will make a decision depends on type of current mode (nominal or degraded). Each diagnoser sends its local decision to a coordinator in each current event $\sigma \in S_{a,o}$. We apply our algorithm on the events set Σ_i of each mode i and the activation sequence $S_{a,o}$. The coordinator manages between the different diagnosers and identifies the current mode with its final decision illustrated in Table 1. So, our system is starting with nominal mode n and passing by degraded mode $d1, d3, d2$ for arriving again at the nominal mode n . The final active mode is nominal mode n in this example. Or, activation of nominal mode is performed by the occurrence of the sequence of commutation events $f_1f_2r_1r_2$. Therefore, our approach ensures to determinate the active mode and to resolve the ambiguity problem.

TABLE 1
RESULT OF ALGORITHM

$\sigma \in S_{a,o}$	$D_n(\sigma)$	$D_{d1}(\sigma)$	$D_{d2}(\sigma)$	$D_{d3}(\sigma)$	Coord
b_1	NF	ND	F_2	ND	(n, n, NF)
b_2	NF	F_1	ND	ND	(n, n, NF)
b_3	ND	F_1	ND	F_1F_2	(n, d_1, F_1)
e_3	ND	F_1	ND	F_1F_2	(d_1, d_1, F_1)
b_4	ND	ND	F_2	F_1F_2	(d_1, d_3, F_1F_2)
e_4	ND	ND	F_2	F_1F_2	(d_1, d_3, F_1F_2)
b_1	NF	ND	F_2	ND	(d_3, d_2, F_2)
b_2	NF	F_1	ND	ND	(d_2, d_1, NF)

V. CONCLUSION

This paper deals an approach completely defined for the management and the change of operating modes applied to discrete event systems (DES) in particular when the process is subject to failure. Proposing architecture of multi-model diagnosis allows us to identify and locate failures when switching occurred. Our current research is attempting to resolve the diagnosability problem in real-time for a complex system.

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