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OVERVIEW OF FAULT DIAGNOSIS METHODS FOR DYNAMIC SYSTEMS

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ABSTRACT

Fault diagnosis in physical systems turn out to become very complex as soon as the considered systems are no longer elementary and become more and more complex and sophisticated, it is then legitimate for companies to acquire an effective diagnosis system.

In our research work, we are interested in the diagnosis of industrial hybrid systems, which are composed of continuous systems, discrete event systems and an interface that manages the interactions between the two aspects. The aim of this paper is, first, to give an overview of hybrid systems, and second, to review the state of the art of methods and techniques for fault diagnosis of hybrid systems.

KEYWORDS: Diagnosis; Hybrid systems; Continuous systems; Discrete event systems.

I. INTRODUCTION

For a long time the automatic has treated separately continuous systems and discrete event systems, for each of these two classes of systems there exists a theory, methods and tools to solve the problems that arise to it. However, the separation between the world of continuous systems and that of discrete event systems is not as clear and most of real systems have both continuous and discrete aspects, these systems are called hybrid systems.

A hybrid system is a dynamic system that exhibits both continuous and discrete dynamic behaviors. In general, the state of a hybrid system is defined by the values of the continuous variables and a discrete mode. The state changes either continuously, according to a flow condition, or discretely according to a control graph. Continuous flow is permitted as long as so-called invariants hold, while discrete transitions can occur as soon as given jump conditions are satisfied.

Recently, we began to be interested in the diagnosis of hybrid systems because they constitute the majority of the industrial systems. In [1], the authors presented a survey of the different approaches to diagnose dynamic systems. The purpose of the diagnosis procedure is to not only determine whether a fault occurs but also to locate the faulty component and thus identify the problem, therefore, the fault diagnosis includes three tasks, that is, fault detection, fault isolation and fault identification. Fault detection is the most basic task of the fault diagnosis, which is used to check whether there is malfunction or fault in the system and determine the time when the fault occurs. Furthermore, fault isolation is to determine the location of the faulty component and fault identification is to determine the type, shape and size of the fault. Clearly, the locations of the faulty components and their severe degrees of the malfunctions described by the types, shapes and sizes of the faults are vital for the system to take fault-tolerant responses timely and appropriately to remove the adverse effects from the faulty parts to the system normal operation.

The paper is organized as follows; in section 2 , hybrid dynamic systems and its different classes are presented. In section 3, we present an overview of the different diagnosis methods for discrete event systems, continuous systems and hybrid systems. Conclusion is drown in section 4.

II. HYBRID SYSTEMS

Technological innovations have had a considerable impact on the emergence of dynamic processes with a heterogeneous nature mixing the continuous and the discrete. These technological advances have a similar impact in the field of scientific research, where there is a particular interest in the study of these so-called hybrid systems. Such systems are characterized by the interaction of the continuous parts presented, generally, by differential equations and discrete parts, described by finite state machines or Petri nets…

Before going away in the presentation of hybrid systems, two preliminary notions must be defined:

Definition 1: A variable is called continuous if it can take its values in a continuous set of values (uncountable) and its variations have no discontinuities.

Definition 2: A variable is called discrete if it can take its values in a countable set of values.

Definition 3: A discrete system is such that all its state variables are discrete and a continuous system is such that all its state variables are continuous.

A hybrid system includes at least: a discrete state variable and a continuous state variable.

In automatic systems, physical systems are often represented by a continuous dynamic model or by a discrete event model. The nature of each model is defined according to the variables used to describe the state of the system and the variable characterizing the time. It is important in many cases to use one of these two categories of models. However, the majority of realistic complex systems mixing continuous and discrete can not be classified either in the continuous system category or in the discrete system category. It is then necessary to use hybrid models allowing the taking into account of both the continuous variables and the discrete variables as well as the interaction between them.

In general, a hybrid dynamic system is composed of a continuous dynamic system, a discrete event system and an interface that manages the interactions between the two evolutions (continuous and discrete).

- The discrete part: It is associated with a discrete event system whose evolution is represented by a finite set of states. The transition from a discrete state to another successive discrete state is achieved by the occurrence of events. These events are of two types: controlled events and autonomous events. The most classical models for discrete event systems are finite state automata and Petri nets.
- The continuous part: The evolution of the continuous part is characterized over a continuous time space and can be represented in different ways (ordinary differential equations, algebra-differential equations, transfer functions, bonds graphs, etc.).
- Interface: It translates the interaction between the continuous part and the discrete part of the hybrid dynamic system. The formal representation of the interface is more complex and depends on the modeling approaches considered.

Several works have focused on dynamic hybrid systems, namely: [2-8], they are classified into six classes:

- ➢ Continuous Systems Supervised by a Discrete Event Controller:

A continuous process, controlled or supervised by a discrete event system, is called a hybrid system by control. This class of hybrid systems is widely studied in the literature[9, 10].

- ➢ Continuous systems with discontinuities

The phenomena of discontinuities occur when the state passes instantaneously from its current value to another value. This phenomenon of commutations is illustrated through the classic example of a rebounding bullet or the collision between two bodies. In both cases, the speed changes sharply and is therefore jumped[11].

- ➢ Systems with discrete and continuous elements

Some systems are intrinsically composed of continuous elements (constrained or produced variables have a continuous evolution) and discrete elements (the constrained or produced variables are of discrete value). Examples of such systems are electronic circuits containing elements with continuous characteristics (resistance, capacitor, choke, etc.) and elements with discrete characteristics (switch, diode, thyristor, etc.) [12].

- ➢ Continuous systems for which discrete dynamics are introduced by abstraction

In some cases where physical phenomena are complex, modeling requires the use of non-linear functions that are difficult to manipulate. Some works propose to introduce discrete phenomena within the continuous evolution in order to simplify the modeling[10, 13].

- ➢ Discrete systems for which continuous dynamics are introduced by abstraction

These systems are generally systems with discrete rich dynamics, that is to say, whose evolution of the discrete state is fast compared to the overall dynamics of the system [14].

- ➢ Complex systems composed of continuous and discrete subsystems

In the so-called process industries, which prepare the raw materials to be worked by the manufacturing industries, production can be carried out continuously or by successive treatments: batch processes. These processes, which are very present in the chemical, pharmaceutical or agro-food industry, include transfer and conditioning sequences belonging to discrete event systems and continuous operations for a certain time (evaporation, crystallization, mixing, etc...)[10].

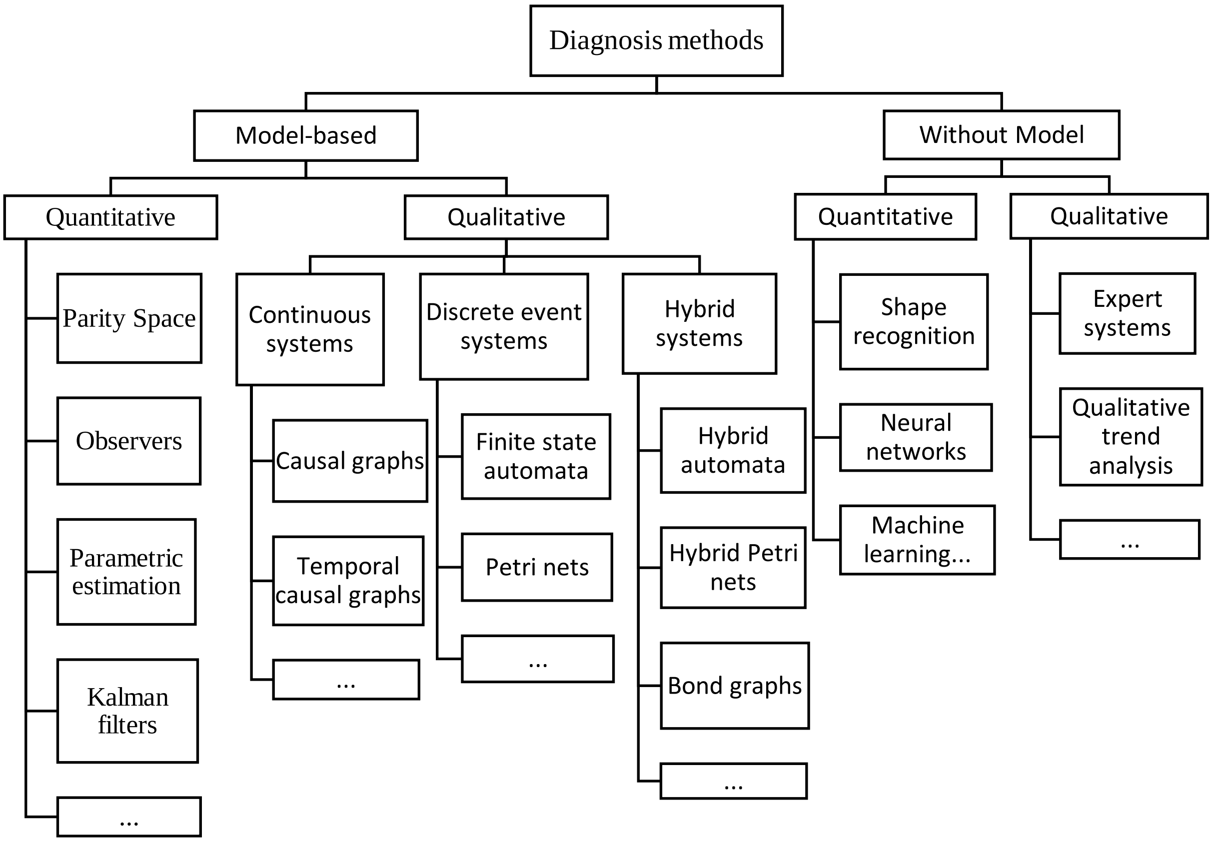
III. DIAGNOSIS OF DYNAMIC SYSTEMS

1. Diagnosis: Models and methods

In most cases, the diagnosis methods are related to the knowledge available on the process and its representation and are classified in different ways by many authors [15-18]. Terminology and classification are not always homogeneous, influenced by contexts and terminologies specific to each community and field of application. Moreover, very often the methods and the models are intimately linked.

On the basis of these considerations, we propose a non-exhaustive classification of diagnosis methods according to two axes: model-based approaches (qualitative methods and quantitative methods) and without-model approaches, namely methods based on data processing (qualitative and quantitative methods). This organization is presented in Table 1.

Table 1. Diagnosis methods



2. Diagnosis of discrete event systems

A Discrete Event System is a discrete state space system whose transitions between states are associated with the occurrence of discrete asynchronous events [19]. These systems cover a wide range of situations, ranging from vehicular traffic (in an urban network or a manufacturing facility) to the operation of machines in a flexible workshop. Several mathematical models have been proposed for the analysis and control of these systems, in particular finite state automata and Petri nets. Some models of discrete event systems, such as timed automata, use temporal variables of a symbolic nature, where time essentially serves to define a chronology between events. To construct diagnosis tools for discrete event systems, different modeling formalisms have been used. We are interested in automata [20] and Petri nets [21].

Diagnosis methods for timed discrete event systems based on timed automata have been proposed by [22] [23] [24] [25] [26] and others. Extensions of diagnosis methods for probabilistic systems have been proposed in [27] [28] [29] [30] [31] [32] and others.

In order to reduce computational complexity by avoiding the exhaustive enumeration of the state space of the system, several diagnosis approaches based on Petri nets have been proposed. Some methods have considered that the marking of certain places is observable as in [33-35] [36] [37] [38] [39] [40] [41] and others considered that the marking is unobservable but the set of transitions is observable as in [42] [43] [44] [45] [21] [46] [47] [48].

The diagnosis of discrete event systems also depends on the decision-making structure. Three main processing structures, or architectures, are used to calculate the fault diagnosis decision: centralized, decentralized [49] [50] [51] [52] [53] [54] [55] [56] and distributed [43] [44] [57] [58] [59] [60].

Note that the distinction between the decentralized and the distributed structures is sometimes blurry. Generally speaking, decentralized approaches have a set of diagnosers, each with different observation capabilities, but all considering the global system model in their model-based inferencing. In distributed approaches, the individual diagnosers only use partial (local) system models as opposed to the global system model [49].

3. Diagnosis of continuous systems

Continuous systems consist of elements characterized by one or more measurements that can take real values as time progresses. The quantities can be, for example, a position, a speed, an acceleration, a level, a pressure, a temperature, a flow, a voltage, etc. The management of these systems uses mathematical tools suitable for the representation of the continuous dynamics like the differential equations. Continuous systems are perceived by the automatic specialist through a representation based mostly on continuous state variables and a temporal variable, continuous or discrete.

The methods developed up to now for the diagnosis of industrial systems are concerned with the diagnosis of linear systems [61, 62]. However, the majority of the systems present in the industry are non-linear. There are no systematic general methods for the diagnosis of such systems. The methods developed for the diagnosis of nonlinear systems are based mostly on knowledge of the behavior of the nonlinear system in question.

The many methods proposed over the years can be classified according to whether they are based on knowledge of the mathematical model of the system to be diagnosed.

Fuzzy approaches [63, 64], approaches based on neural networks [63] or by stochastic analysis of the signals [65] are not considered model-based approaches. Model-based approaches include, the parity equations [61, 66-69], parametric identification [15] [70] [71] and observers [72] [73] [74] [75].

4. Diagnosis of hybrid systems

Hybrid Dynamic Systems cover simultaneously both continuous and discrete aspects. These systems evolve over time and combine continuous and discrete variables [76]. A discrete state of the system can be seen as a continuous system with continuous variables connected by constraints. However, the scope of these constraints is limited to the state in question. The transition of the system from one state to another changes its mode of operation by making it subject to other continuous laws proper to the new state.

The effectiveness of a diagnostic method for hybrid dynamic systems can be measured by its ability to optimally exploit the two aspects presented by these systems: the continuous aspect through the continuous state variables and the discrete aspect through discrete events. Usually, these two aspects are approached by different approaches, from continuous systems or discrete event systems. Indeed, the detection of an abnormality on a continuous state variable is performed when it exceeds a certain threshold, and on a discrete variable when the occurrence of an unexpected event occurs, or when an expected event does not happen.

4.1. Contributions based on continuous approaches

Diagnosis approaches from the community of continuous systems are such that residue generation and causal graphs, the use of the discrete aspect of hybrid dynamic systems is generally weak in these approaches.

Several diagnosis approaches based on the generation of residues have been proposed in the literature. We we can hold up as an example the approach of [77]. In this approach, the on-line estimation of the mode of functioning of dynamic hybrid systems is carried out by to the use of Petri nets. The occurrence of a fault is detected by comparing the measured quantities with those expected, taking into account the commands sent to the process. The diagnosis of the state of the process is then carried out using a logical tree. This approach, adapted to dynamic hybrid systems, has the advantage of detecting anomalies due to continuous variables and the occurrence of disruptive events.

Another diagnosis technique for dynamic hybrid systems has been proposed in [78]. This technique relies on diagnosis methods based on analytical redundancy. The system to be diagnosed is modeled by a hybrid automaton. Fault diagnosis is made from structured residues specific to each fault.

In [79], a solution is proposed based on the use of a hybrid observer consisting of a continuous observer and a discrete observer. The discrete observer makes it possible to identify the current discrete state of the system while the continuous observer estimates the evolution of the continuous variables. In [80], Gomaa proposes a dynamic hybrid system diagnosis approach based on an extension of the hybrid Petri nets, called the Hybrid Continuous Petri nets. This model integrates three types of Petri nets. A continuous time-delayed Petri net called the hybrid continuous Petri net (RdPC2H), it is an approximate model causally modeling the continuous part of the dynamic hybrid system. A conventional Petri net modeling the control system (discrete event system); and a conventional Petri net modeling the interaction between the continuous part and the control system. The causal links (transitions) between the continuous variables are represented through qualitative transfer functions based on the gain, delay… The fault detection system, which influences the continuous variables, is performed asynchronously; the back / front chaining of the causal links between the variables using their temporal information carry out the location of defects.

Another approach based on causal reasoning was proposed in [81]. This approach is based firstly on the modeling of the system by a hybrid bond graph [82] and then the generation of a defect propagation graph, which makes it possible to describe the causal and temporal relationships between the different defect modes on one side and the associated observations of another.

4.2. Contributions based on discrete event system approaches

There are few diagnosis contributions for dynamic hybrid systems, derived from discrete event systems methods. Indeed, the development of such methods is in confrontation with the complex dynamics and the indecidabilities linked to the dynamic hybrid system. We can identify two main approaches in this context: Lunze's Diagnosis approach and discrete time hybrid model approach.

Lunze proposed in [83] diagnosis algorithms similar to the concept of the diagnoser of Sampath. Thus, the inference and the evaluation of the hypotheses on the defects are carried out through a diagnosis algorithm. The problem of diagnosis is associated with a problem of observation of qualitative state. Indeed, a qualitative abstraction of the continuous variables of the system is carried out through the use of quantifiers.

An extension of the Sampath approach for the diagnosis of discrete time hybrid systems has been proposed in [84]. The considered model evolves as a timed automaton with n different flows [85]. It is represented by an activity transition graph, where each activity corresponds to a vertex of the graph. The evolution of the continuous variables in each activity is synchronized to the occurrence of a special event, called tick, that occurs after each constant period. On the occurrence of a tick, each variable evolves with a constant step, defined according to its dynamics. The variables are divided into discrete variables (or events) observable and non-observable and measurable and non-measurable continuous variables. The diagnostic approach begins by modeling system components using activity transition graphs, then obtaining the global model by the composition of these models. The Diagnoser is an activity transition graph, compiled offline. Each vertex of the diagnoser contains an estimate of the system state and the labels of the set to indicate the presence of defects.

IV. CONCLUSION

The issue of diagnosis covers a very wide area and has been the subject of many researches. Two different scientific communities, namely continuous systems and discrete event systems, have contributed to the development of methods for detecting and locating defects, the aim of which is to guarantee optimal safety for industrial installations.

In this article, we have given a global view of dynamic hybrid systems and we have presented some works that are interested in the diagnosis of dynamic systems.

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