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Identification of abnormal events by data monitoring: Application to complex systems

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ABSTRACT

Many maintenance actions, such as mechanical, electrical, and hydraulic skills, are mandatory to maintain complex systems in operational conditions. Considerable research has been conducted in these fields to optimize maintenance actions. Most research proposes approaches based on physics: physical model of a specific failure, law of aging, etc. In spite of their performance, these approaches are quite difficult to implement on a complex integrated system. Each field of expertise assesses the good health of a system part using its own experts, its own methods, and, in some cases, its own data. Nevertheless, these fields all make up the same machine, and no interaction between systems is considered. Our study is not based on physical approaches but uses operational data and mathematical tools to diagnose, off-line, the current state of the system. The proposed paper concerns a new concept consisting in characterizing normal system functioning by using data recorded during monitoring. The life profile of this complex system is described by employing all the available data to determine, on the one hand, all normal events and, on the other, to identify abnormal events according to their position compared to the normal envelope defined. The recorded data are then specifically analyzed to characterize the level of criticism of an event considered to be abnormal. This abnormal event could then be assimilated to a global behavioral drift of the studied behavior, which is different to usual behavior. This approach is applied to helicopters by use of all flight recorded data.

1. Introduction

In sensitive systems such as aeronautics, space or even the automotive industry, safety performances have been increasingly enhanced and need to be more so in the future. Today, aircraft manufacturers are trying to increase cost benefits through the implementation of technical solutions such as health monitoring, efficient diagnosis, or condition-based maintenance. These improvements call for the development of robust approaches. However, the increasing complexity of systems makes such developments difficult to maintain. As it is more complex to identify and localize failures and degradation, we need to find a solution enabling us to identify causes of failures and to model degradation evolution. This paper focuses on the reasons for failures and degradations, which lead to maintenance operations. The problem is to identify when maintenance operations should be performed. Unlike much literature focused on solutions for optimization of maintenance, this paper concerns recognition of normal operations and abnormal events, and the deviations from this behavior considered to be good [21], in other words it presents the concept of the "normal envelope". The proposed approach allows us to detect and characterize an event that is potentially abnormal for the system. It concerns the proposition of a new two-step concept based on data mining tools. The first step corresponds to characterization of normal system functioning, while the second step consists in identifying abnormal events according to their position compared to normal usage of the system.

In recent years, maintenance has become one of the main priorities of manufacturing industries. In actual fact, maintenance is the most expensive task in the product life cycle, with more and more manufacturers in different areas working to elaborate technical solutions and associated technologies to cut maintenance costs. At the same time, although much research has been conducted to optimize maintenance actions, integration of several

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functionalities makes the systems increasingly complex and difficult to maintain. A number of works contribute to the improvement of maintenance or diagnosis actions, such as the following approaches:

- Avionic diagnostic methods have been improved by [15] and [20]. Their goal was to reduce false alarms by using dynamic fault trees. New dynamic gates of fault trees, which include time values for detecting specific sequences of events, are defined in [14]. The methodology proposed includes the dependencies between fault events in the models. Thus, two problems are solved, namely filtering of false alarms, and reduction in size of fault isolation ambiguity related to the occurrence of a failure. In [2], authors propose an effective way for diagnosing discrete-event systems using a timed-automaton with application to the aeronautic field. A dynamic model with temporal transitions is proposed to model the system. The diagnosis method is based on the coherence between fault occurrence time and defined reverse path length [8].
- Failure prognostic was studied by [9]. These studies attempt to assess the remaining life time of avionic equipment by using temperature and vibration cycles. Works concern a health monitoring methodology to provide associated prognostic information. A new methodology allowing estimation of life consumption monitoring based on temperature impact, is proposed.
- Condition-based maintenance is a maintenance concept in expansion described by [16]. The authors propose an approach to provide the required inputs for definition of the future health management structure, allowing customized maintenance planning adapted to actual usage of the aircraft. Monitoring such usage allows expansion (or reduction) of time between predictive maintenance operations.
- In [19], the aim is control of product aging. A method based on numerical integration of the resulting bilinear equations is used to obtain approximate time histories of the motion.

Each of these methods is dedicated to a specific field. In this paper we propose a new concept corresponding to the normality of operation. By using heterogeneous operational data, a method is proposed that can identify an envelope representing correct or expected functioning. If, at any given time, the treated data are not within this envelope, the system is considered to be abnormal, and the degrees of removal will correspond to the level of criticality of the failure.

After a brief presentation of the context and the problems involved in the aeronautic field, the data classification method in the learning step is presented together with the tools used. The principle of constructing a normal envelope is described step by step in Section 3. Section 4 is dedicated to utilization of the normal envelope. The proposed approach is illustrated in an example of a complex system: Helicopter. Finally, a conclusion will round up this paper.

2. Context and problems

System diagnosis methods must comply with the changes in component technology. Most methods present limits and, more particularly, those based on models. While such methods are effective for taking into account the physics of failures, they are not easily applicable to heterogeneous complex systems. Moreover, in spite of their performances, physical approaches are difficult to implement on a complex system, as merging of all sub-systems to define the system raises many difficulties. Every interaction between sub-systems has to be identified and modeled, and identifying them all is no easy task. Another problem faced by this kind of approach is its reproducibility. Constructing a physical model of a complex system is expensive, time-consuming, while considerable tuning is mandatory to enable adaptability to another system. Consequently, our study is conducted alongside physical approaches, and is based on operational data and mathematical tools to assess the current state of the system.

Generally, a system is said to be complex when it contains several functionalities, each of which requires a particular expertise. We are concerned here with complex systems made up of different parts, where each part has its own field of expertise, experts, methods and architecture (Fig. 1).

In an industrial context, implementation of operational data feedback raises many difficulties [13]. In this paper, we focus on the data analysis step, the difficulty of which is related to the following assessment:

- *Quantity of data*: difficulties consist in extracting interesting information from a substantial amount of data.
- *Heterogeneity of data*: each type of data needs to be processed appropriately. However, mathematical tools do not distinguish between the different data types. Consequently, analysts must fully understand the processing required. For example, a large amount of data can be collected in manufacturing processes involving extremely complex processes and particularly susceptible to specific environments, requiring a high level of stability such as semiconductor manufacturing. Another case is the aeronautic field, where a large amount of helicopter in-service data are collected from customers. Most of this information is recorded on board, by embedded equipment, when the helicopter is on a mission. These data types are heterogeneous: failure code, vibration data, acoustic data, usage and flight data, etc. The remaining part of this information is provided by customers who operate the system: maintenance operations and overhaul data, flight reports, etc. Flight data are made up of information such as: temperature, pressure, command position, rotor speed, altitude, fuel flow/quantity, weight, etc. As these data are representative of environmental contexts and helicopter behaviors, this information could be useful for each field of expertise. To improve maintenance performances, consideration of this kind of data is a good method. However, it raises many difficulties.

Irrespective of the level of complexity of a system, monitoring data heterogeneity complicates data use. Furthermore, as data volume is large, monitoring data must be classified. Utilization of data monitoring can be simplified in two ways:

1. Reduce the quantity of data.
2. Synthesize the main information.

Data mining offers a wide range of specific tools to tackle these problems. Utilization of these data depends on their origin.

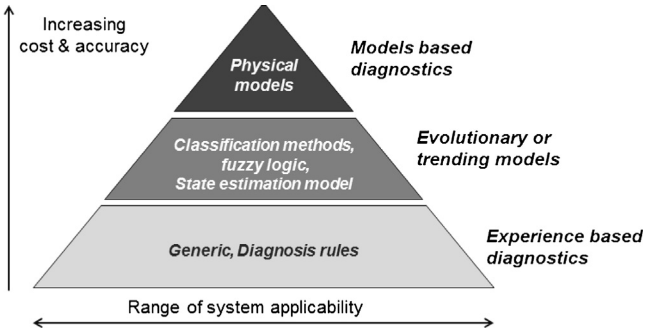

Fig. 1. Diagnostic approach classification [2].