Aerospace Science and Technology 46 (2015) 339–350

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Diagnostic and decision support systems by identification of abnormal events: Application to helicopters

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ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 27 July 2015
Accepted 31 July 2015
Available online 5 August 2015

Keywords:
Customer feedback
Data mining
Diagnostic
Statistical data analysis
Trends monitoring
Maintenance

ABSTRACT

Today, aircraft manufacturers are trying to improve costs benefits by the implementation of technical solutions like health monitoring, efficient diagnosis or condition based maintenance. These improvements need to develop robust approaches. However the growing complexity of system made maintenance difficult. It is more complex to identify and localize failures and degradation. In consequence, trying to work on causes of failure and degradation should be interesting. This paper focuses on the reason of failures and degradations which lead to maintenance operations. Most of researches proposed are based on physics: physical model of a specific failure, law of ageing, etc. In spite of their performances, these approaches are quite difficult to implement on a complex integrated system. Each field of expertise assesses the good health of a helicopter part by 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 helicopter utilization by used flight data. The life profile of the helicopter is described by employing all the flight data available 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. Flight data are then specifically analyzed to characterize the level of criticism of an event considered to be abnormal. This abnormal event could be assimilated to a global behavioral drift of the aircraft, a behavior which is different than usual.

1. Introduction

The mastery of maintenance is a key element in the quest for competitiveness of helicopter manufacturers. Much research has been done to improve performance, either to increase machine availability, increase security, and reduce costs. This research, relatively specific, has advanced and evolving methods of detection, diagnosis, and sometimes failure prognosis [28,23,11]. They led to what today is the maintenance of helicopters, relevant and effective maintenance decomposed by subsystem. Thus, to determine the overall health of the helicopter system, the maintenance operator must be able to know the state of health of each subsystem, put them together and analyze them. This task is time consuming for several reasons:

– Each subsystem has its own characteristics, methods experts, architectures and tools. This reality stems from difficulties, acquisition and analysis of the results of fault detection methods, diagnosis and prognosis.
– The subsystems are part of the same set and are interconnected. Causes and effect relationships, implicit or explicit, and exist because of the segmentation analysis, they are not easily addressed.

To abstract from these difficulties, it would establish a new method for assessing the overall health of the helicopter. This method, focusing on assessing the health status of the system, cannot be precise as a focusing method on a subsystem. However, the focus on the whole machine can consider the links between the various subsystems. Therefore, we will try to identify the normal behavior of the machine and identify deviations with respect to this normality [15,25].

We have seen that the methods of exploration data can extract relevant information from a large volume of data. These methods without a priori may be used to extract from the historical data, a

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http://dx.doi.org/10.1016/j.ast.2015.07.024

normal behavioral pattern of the system. So we will try to answer the following two questions:

- How to extract a historical data, a model representative of the normal system behavior?
- How to detect and characterize an abnormal phenomenon from a model of the normal behavior of the system?

The problem is to identify when maintenance operations should be performed. Unlike much literature focused on solutions for optimization of maintenance, this paper concerns the recognition of normal operations and abnormal events, and the deviations from this behavior considered to be good [25]. 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 aircraft. It concerns the proposition of a new concept based on data mining tools, consisting of two steps. The first step corresponds to the characterization of normal usage of the helicopter, while the second step consists in identifying abnormal events according to their position compared to normal helicopter usage.

In this article, the first part presents what "the helicopter normality" and details the steps needed to build the representative model of the so-called normal behavior. As for the second part, it concerns the operation of the normal pattern of behavior. For simplicity, the first part will introduce the learning phase of the model while the second part will detail the operational phase of the said model. The objective of this article is to provide the scientific, architecture to model to detect and characterize abnormal system behavior. 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. Finally, a conclusion will round up this paper.

2. Related works

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 [16]. At the same time, although much research has been conducted to optimize maintenance actions, integration of several 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 [18] and [23]. 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 [17]. The methodology proposed includes the dependencies between fault events in the models. Thus, two problems are solved, relating to filtering of false alarms, and reduction in size of the ambiguity of fault isolation 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 the fault occurrence time and the defined reverse path length [9,24].
- Failure prognostic was studied by [10]. Their studies attempt to assess the remaining life time of avionic equipment by using temperature and vibration cycles. The works concern a health monitoring methodology to provide associated prognostic information. A new methodology allowing estimation of life consumption monitoring based on the impact of temperature is proposed.
- Condition-based maintenance is a maintenance concept in expansion described by [19]. The authors propose an approach to provide the required inputs for definition of the future health management structure that will allow customized maintenance planning adapted to the actual usage of the aircraft. Monitoring the real usage of the aircraft allows expansion (or reduction) of time between predictive maintenance operations.
- In [22], the aim is control of product ageing. A method based on numerical integration of the resulting bilinear equations is used to obtain approximate time histories of the motion.

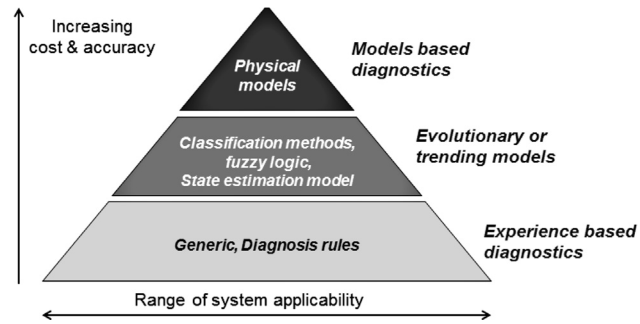

Fig. 1. Diagnostic approach classification [2].

Each of these methods is dedicated to a specific field. In this paper we propose a new concept which corresponds to the **normality of operation**. By utilizing heterogeneous operational data, a method able to identify an envelope representing correct or expected functioning is proposed. If, at a 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.

3. Context and problems

System diagnosis methods must follow evolution of component technology. Most of them present limits and, more particularly, those methods based on models. While they are effective methods which take 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 the merging of all subsystems to define the system raises many difficulties. Every interaction between subsystems has to be identified and modeled, and identifying all of them is not obvious. Another problem faced by this kind of approach is its reproducibility. Constructing a physical model of a complex system is expensive, time-consuming, and 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. (See Fig. 1.)

In an industrial context, implementation of operational data feedback raises many difficulties [15]. In this paper, we focus on the data analysis step, the difficulty of which is related to the following assessment: