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Embedded holonic fault diagnosis of complex transportation systems ☆

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ABSTRACT

The use of electronic equipment and embedded computing technologies in modern complex transportation systems continues to grow in a highly competitive market, in which product maintainability and availability is vital. These technological advances also make fault diagnosis and maintenance interventions much more challenging, since these operations require a deep understanding of the entire system. This paper proposes a holonic cooperative fault diagnosis approach, along with a generic architecture, to increase the embedded diagnosis capabilities of complex transportation systems. This concept is applied to the fault diagnosis of door systems of a railway transportation system.
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1. Introduction

To deal with the complexity of modern transportation systems (e.g., commercial aircrafts, trains, ships), an efficient maintenance strategy is essential for maintaining and improving the availability and reliability of assets, while minimizing maintenance and total life-cycle ownership costs (Discenzo et al., 2002). Normatively, maintenance is classified as preventive or corrective maintenance (DIN EN 13306, 2010). While preventive maintenance focuses on reducing the probability of failures by replacing components before they fail, corrective maintenance has the objective of returning an item back to service after a failure occurrence. Before any corrective actions can be taken, one of the most time-consuming step of corrective maintenance is the *fault diagnosis* procedure, which consists of identifying the faulty components to be repaired (Feldman, 2010; Khol and Bauer, 2010).

Unlike diagnosing complex industrial systems and static machines, several considerations must be taken into account when diagnosing complex transportation systems. In this paper, we assume that complex transportation systems are characterized by the following properties:

- System complexity—a complex transportation system is assumed to be decomposable into a set of interacting sub-systems, composed of a control part and a controlled part. These sub-systems are designed by several suppliers, using computational and physical components, and heterogeneous technologies (e.g., electrical, mechanical, hydraulic, pneumatic, hardware and software parts) (Dievart et al., 2010).
- System variability—the sub-systems may differ from one system to another (e.g., change of suppliers, design changes, product evolutions) (Azarian et al., 2011).
- System environmental context—each sub-system is assumed to have its own context, which can be either physical (e.g., climate impact, vibrations, electromagnetic disturbance) or informational (e.g., functioning mode, component states) (Monnin et al., 2011).
- System maintainability—a complex transportation system is usually linked to a stationary maintenance center and needs to communicate with it (Jianjun et al., 2007). In addition, maintenance operations cannot be executed immediately in the system (Umiliacchi et al., 2011).

To allow the diagnosis of this kind of complex transportation systems, a diagnosis system must be defined. This diagnosis system must not interfere with the normal operation of any

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sub-system. This no-intrusiveness constraint is mandatory. In this paper, a diagnosis system is assumed to fulfill the following requirements:

- Accuracy—the diagnosis system must be adapted for isolating uniquely the faulty components among various interconnected sub-systems.
- Ease of explanations—the diagnosis system must allow a user to understand how the diagnosis procedure came to the results.
- Adaptability—the diagnosis system must be adapted when changes in components and sub-systems design occur.
- Reactivity—diagnosis results must be delivered in a timely manner to the maintenance center in order to improve the maintenance management.
- Confidence—the diagnosis system must avoid producing false alarms.

Through the continued advances in infotronics and in communication technologies (Clarhaut et al., 2011), intelligent diagnosis systems based in particular on artificial intelligence (AI) and multi-agents (MAS) allow the diagnosis procedure to be automated on-line, observing continuously the system (Campos, 2009; Ng and Srinivasan, 2010). In this context, the main contribution of this paper is to propose a fault diagnosis approach that supports all the previously introduced assumptions. This approach is applied within a joint research-industry project, called SURFER (*SURveillance active FERroviaire*, translated as "active train monitoring"), led by Bombardier-Transport. The aim of the SURFER project is to provide a more advanced solution for the on-line diagnosis of incipient failures and faults that can occur during the train service, besides the existing ORBITA system developed by Bombardier-Transport in 2006 (Orbita-BT, 2006).

This paper is organized as follows. Section 2 presents a literature review about condition monitoring and diagnosis standards, along with the main diagnosis methods. This section highlights the limits of currently-used diagnosis approaches, emphasizing the need of a robust embedded diagnosis. Section 3 proposes an embedded decentralized cooperative fault diagnosis approach, based on a generic holonic model. Section 4 applies the proposed embedded diagnosis model for advanced fault diagnosis of train door systems, within the context of the SURFER project. Section 5 presents the experimental platform used for the implementation of the holonic diagnosis architecture. Section 6 exhibits the first results obtained in the implementation in a real train. Finally, Section 7 offers conclusions and perspectives for future research.

2. Condition monitoring for diagnosing transportation systems

A condition monitoring system involves raw data acquisition, processing, analysis and interpretation of faults to provide useful maintenance information (Campos, 2009). In this section, we refer to condition monitoring as a means of applying on-line fault diagnosis procedure to a complex transportation system, focusing on diagnosing abrupt faults rather than diagnosing incipient faults or performance degradation. Then, the literature is surveyed on condition monitoring, diagnosis standards, and diagnosis architectures. Next, the main diagnosis methods are analyzed. According to the requirements of a diagnosis system, first a diagnosis architecture is chosen, followed by the selection of a relevant diagnosis method.

2.1. Condition monitoring and diagnosis standards

The reference standards for condition monitoring in industry and transportation have been registered under the ISO 13374. This standard defines a generic model of a condition monitoring architecture, using six-layer processing blocks (ISO 13374-1, 2003). These successive layers progress from raw data acquisition to useful maintenance advisories, as the data evolve into information. The layers defined by this standard are: (1) data acquisition, (2) data manipulation, (3) state detection, (4) health assessment, (5) prognostic assessment and (6) advisory generation. In the prescribed model, the first three layers are assumed to be technology-dependent on the monitored system. From there, the diagnosis layer #4 (health assessment) may handle incipient or abrupt faults, while the prognosis layer #5 is specific for incipient faults analysis (IAEA, 2007). The last layer aims at delivering recommendations on maintenance actions or operational changes based on information delivered by lower layers.

2.2. Condition monitoring and diagnosis architectures

Focusing on the diagnosis layer of the prescribed model (i.e, layer #4), Fig. 1 illustrates the two fundamental partitioning approaches: *off-board diagnosis* and *on-board diagnosis* (Alanen et al., 2006; Bengtsson, 2003).

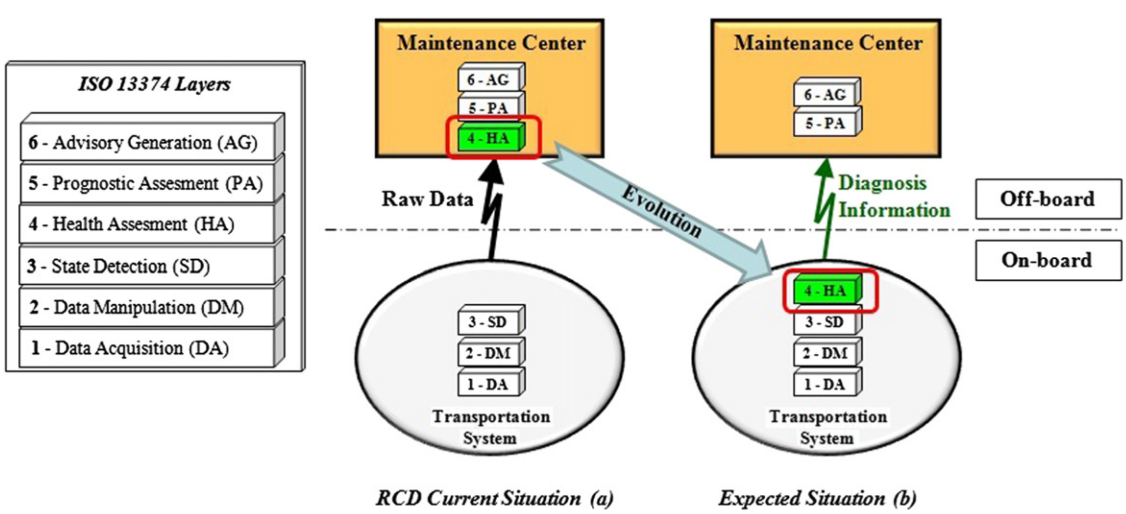

Fig. 1. Diagnosis partitioning: (a) off-board diagnosis and (b) on-board diagnosis.

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