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A new strategy for automotive off-board diagnosis based on a meta-heuristic engine

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ABSTRACT

The automotive industries lack of solutions for accurately, comprehensively and efficiently fault localization. However, such services in the after-sales networks are crucial to the brand value of automotive manufacturer and for client satisfaction. In this paper, a new approach for the off-board diagnosis is presented, with significant improvements compared to the current technologies usually based on inference rules. A more robust approach that allows, per the additions of functional modules, to enhance traditional computer aided diagnostic systems towards a global diagnostic engine reasoning on different sources of knowledge with their uncertainties.

Once the design of a new vehicle has begun, information like the dependencies between the components could be re-used for the models dedicated to the diagnosis task. Moreover, the economic pressure leads to a high degree of innovation with a massive use of electronics in safety, comfort and entertainment (OCC'M Software GmbH, 2010). This dramatically increases the amount of data to manage for the testing of E.C.U. (Electronic Control Unit) functionalities. The complexity of the subsystems leads to breakdowns that need qualitative symptom description for the fault localization. Finally, a feedback engine automatically completes the expensive models for the diagnosis and returns critical dysfunctions to the design department.

In this paper, we present our research on a new diagnosis strategy for complex mechatronics systems. It encompasses the needs and requirements of automotive manufacturer. The results are presented with data obtained from low, middle and luxury class vehicles. They demonstrate the performance in real field conditions of our approach. They are based on the interpretation of observations, the fault localization and isolation, the evaluation of feedbacks for model auto-completion. The novelty in this approach is based on the reasoning of different sources of knowledge (construction and design knowledge, expert knowledge, return of experiences) which leads to an efficient diagnosis. The approach approximates the optimal path from the observations toward the fault isolation with the help of a meta-heuristic engine. These experiences show the potential of our proposed approach for the automotive off-board diagnosis task.

1. Introduction

It has been repeatedly reported that computer aided diagnostic tool's accuracy and efficiency depend on the quality of the models used (Baumeister and Seipel, 2002). Current techniques are based on expert systems or a combination between the last and a Case Base Reasoning engine (Cornelius, 2004). Model based diagnostics are very accurate but time- and labor-demanding, and therefore too expensive to be comprehensively applied in workshops (Chieux and Guillaneuf, 2005; Leen and Hefferman, 2002). Therefore, there is a need in the automotive industry for effective and efficient off-board diagnosis especially considering the upcoming new technologies (Trevett, 2002) such as X-by-Wire, Electric and hybrid engines, Car to car communication, RFID (Radio Frequency IDentification) or wireless sensors (Shen et al., 2010), that rely strongly on dependent components. Moreover, in order to distinguish the products of car manufacturers, clients customized their cars which lead to a combinatory explosion of vehicle variants where only some have identical subsystems. This section is divided into 3 parts beginning with a summary of existing research, strategies and tools followed by a presentation of the problem statement and objectives of our contribution. At least a brief description of our industrial platform used for the experiences is given in form of an overview.

1.1. Existing research

Many research initiatives are investigating the fields of diagnosis allowing a progression in efficiency, in particular: model based diagnosis which to improve the precision of the fault localization (Gigon et al., 2009), qualitative reasoning which handles incomplete models (Struss, 2003), and distributed diagnostic agents which process parallel information (Biteus et al., 2008; Wen et al., 2003).

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1.1.1. Computer aided diagnosis tools for automotive systems

Several knowledge based systems have been proposed for the diagnosis task (Denton, 2006; Tyler, 2007; Ueno et al., 1992). Their general strategies rely on (qualitative or quantitative weighted) inference rules or a combination of expert rules with a case base (see Fig. 1). One common problem encountered with those strategies is that the diagnostic knowledge is encoded in a rule (Struss, 2003) which is vehicle dependent. If we consider the symptoms: "the headlight does not work", it could be linked to the engine battery (for a low class car with only one battery) or with the comfort equipment battery (for a high class car with 2 power supplies). The second test for the confirmation or rejection of the hypothesis of a faulty battery will be to start the engine in the first case or any entertainment equipment in the second case. The construction of the diagnostic tree (hypothesis and tests), varies with the car configuration. The MBD (Model Based Diagnosis) technology consists in comparing the actual behavior of a system, as it is observed, with the predicted behavior of the system given by a corresponding model (see Fig. 1).

A discrepancy between both state (observed and predicted) is a clear indication that a failure is present in the system. However, the reasoning with an MBD engine would allow to identify which test had to be performed to confirm an hypothesis. With the precedent example if in both cases the power supplies and their connections are modeled, the diagnostic engine can immediately determine the actuators (or equipment) to test (the motor engine or any entertainment component) and **provide an explanation** of why this test is performed (based on the construction knowledge or in the example the wiring diagram of the power supply). Case based reasoning engines also encountered a great success in the industry. They are adequate to reason on global diagnostics in automotive cases (Azarian, 2009), like for example a faulty ECU engine management (which initiates around 60 fault codes in ECUs of a modern car (Ertz and Ohne, 2008)). But for hypothesis refining, it is difficult to find a global similarity metric or to ignore certain attributes in the case description after a global test. Despite the quick response time of CBR and the widespread covered physical domain, it is not adequate with the requirement of the automotive industry which needs the models of new vehicle to be operational in the workshops before the start of the commercialization (meaning without any Return Of Experience, ROE). Moreover, CBR (Mohamed et al., 2002) does not provide any explanation about the delivered results, and does not handle the configuration problems of modern vehicles. Wen et al. (2003) proposed a distributed diagnosis agent structure with an engine reasoning from global diagnostics. The state of the system composed by n diagnostic agents can consequently be described by signature vector. The discrimination comes from the comparison of the current signature with the one from known problems. The interesting aspect of this approach is that the distance between the different states (or coordinates of the signature) can be computed considering the constraints of the states as "undefined" or "not disposal". This aspect is very valuable in automotive problems, where often some electronics components cannot return a signal or due to a missing value in the database the signal returned cannot be interpreted as a known state. This is a weakness of CBR engines which could be resolved with the help of plausibility tests (Biteus et al., 2009).

Furthermore, the role of the technician whose problem solving behavior is subjective and complex in the diagnosis task cannot be neglected. In today's knowledge economy, the need to manage the knowledge produced by the actors of the diagnosis task cannot be ignored and should be overemphasized in the diagnosis algorithm. For a complete manufacturer's after sale network, the protocol of the performed diagnosis sessions reaches 10,000 a day for a country like Germany (Azarian, 2009). Thus making it a valuable source of knowledge in solving diagnosis cases if capitalized for future re-uses. Most of the engineering methods employ their own reasoning technique. The case base reasoning engine implements a case base made up of cases containing solutions that were used to solve old problems. This necessitates knowledge representation techniques (or formalization) for the case representation, building and acquisition. The CBR feasibility for decision help in industrial supervision was shown by Mille et al. (1999) and a practical study by Rasovska et al. (2008) for maintenance and diagnosis of industrial equipment shows a precision of 95% in problem solving. A statistical analysis of the sales of BMW (Biteus et al., 2009) reveals that less than 1% cars are identical, that implies a real challenge in the editing and updating of the vehicle model (knowledge representation and acquisition) in automotive diagnosis tools. Hence the advantage of ontology techniques for the creation of case representation shows several advantages in such cases as reported in a study by Bergmann and Schaaf (2003). This method shows promising results considering the growing size, complexity and interoperability of knowledge in industrial systems. The work of Kamsu Foguem et al. (2008) relates to the structuring and the formalization of an experience feedback process aiming at transforming information or understanding gained by experience into explicit knowledge, using ontology as a framework for the clarification of explicit knowledge and know-how.

For the facilitation of assessments and comparison of diagnosis technologies the NASA has developed Advanced Diagnostics and Prognostics testbed called ADAPT (NASA Ames Research Center,

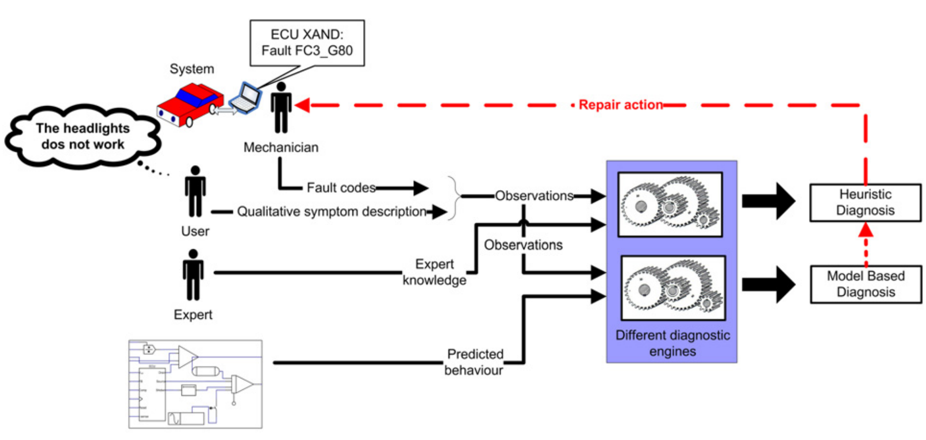

Fig. 1. Illustration of MBD principle applied in automotive industry.