Off-Board Model Based Diagnosis: Multimodel approach for the automatic generation of test sequences

Application to automotive systems

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I Motivations

Diagnosis is the process of identifying the cause (fault) of a system's failure by observing it at various monitoring (test) points. The number of possible causes of failures has increased with the technological advances of systems while reduction in the number of monitoring points results in reduced fault observability, making it increasingly difficult to troubleshoot these systems.

In the automotive domain, the use of electronic systems (ECU) to control several functions is widely spread. These functions span diverse automotive areas such as engine control, breaking, driving, comfort and security. So, the task of garage mechanics is not simply limited to mechanical repairs, but also involves electronic ones. Diagnostic tools are hence needed to help the mechanics in the diagnosis task of electronic systems.

Currently, the existing tools are based on diagnosis trees that are made by human experts. This task is time consuming, laborious and errors are not unusual.

II Research Objectives

The thesis, supported by a CIFRE grant, is a joined work between the LAAS-CNRS research centre and the ACTIA Company. It is part of a project of the Joint Lab AUTODIAG. The work aims at providing an operational model based method to the problem of determining the best test sequences to be performed by the garage mechanic so that a fault is localized with minimum time and cost. This method must account for observations at different levels of knowledge: functional symptom, visual observation, electrical measurements, qualitative knowledge…

III Context and positioning

Off-board diagnosis is performed on a failed vehicle on a workshop test bench. The fault is supposed to have been detected and the vehicle to be diagnosed is in the garage. The problem to be solved is known as the *test sequencing problem*. It was formulated for binary tests in [7] and extended to multi-valued tests in [5][6][6]. Following a fault dictionary approach, tests are proposed from the knowledge of the effects of a set of anticipated faults compiled in the form of a Fault Signature Matrix. The Fault Signature Matrix is the result of a prediction step.

This annual Workshop DISCO report is the third one and corresponds to the work of the last year of my thesis which must be presented during the second trimester of the year 2008. Three axes will be developed in the final memory.

III.1 Hierarchical modelling

The increasing complexity of engineered systems has led the Model-Based Reasoning (MBR) community to investigate the use of multiple abstraction level models organised through a hierarchy to support the diagnosis reasoning task. Abstractions are useful to reduce the computational complexity of diagnosis reasoning, to account for qualitative observations at functional levels, and to handle systems whose available knowledge about components is heterogeneous.

Several works agree that a functional hierarchy consists in a distinction between four epistemological types :

- *Structural knowledge*, which is the knowledge about system topology (Electrical diagrams).
- *Behavioural knowledge*, which describes the physical laws underlying the behaviour of components composing the system.

- *Functional knowledge*, which describes the roles that components may play in the process in which they take part.
- *Teleological knowledge*, which describes the goals of the system intended by its designer.

The functional knowledge level aims at bridging the structural and behavioural knowledge on one side and the teleological knowledge on the other side. In our approach, the system is first considered at structural and behavioural levels. The bottom level models are applied to a prediction mechanism (simulation engine) and the results are then abstracted at the teleological level in order to exhibit corresponding functional observations. A similar approach can be found in Snooke and Bell's [2][9][10]} works in which the system is simulated qualitatively and abstracted for functional and teleological understanding. However, Snooke and Bell target design analysis tasks instead of diagnosis test generation. Summarizing, the observations at each level are computed as follow:

- The simulation, made at the behavioural level, computes quantitative values for physical variables.
- At the functional level, the quantitative values are abstracted into qualitative values.
- At the teleological level the quantitative values are abstracted into semantic labels.

III.2 Abstraction of dynamic tests

In previous works [5][6], static simulations were investigated. Their outputs provided a constant expected outcome for each test and assumed the use of a multimetre tool to actually perform the corresponding tests on the vehicle. In case of hybrid systems, such approach is too limited:

- A measurement with a multimetre implies that the system stays in a given steady state so that a constant value can be measured for the test variable.
- A fault can affect the nominal behavior sequence, eventhough it does not affect the test variable magnitudes.
- For some critical faults, downgraded sequential behaviours are anticipated at design phase.

In our approach, dynamic simulations are investigated and the outcomes are signals across time. These signals must be abstracted from behavioural to functional and teleological levels and this abstraction must include the notion of time and sequence… It can be done by abstracting signals into sequences of qualitative episodes at the functional level and sequences of semantic labels at the teleological level. Some algorithms already exist and are mainly based on the first and second derivatives which provide information on trends and curves of a signal [4].

III.3 Test sequencing strategy

There are two alternative points of view to the test selection problem:

- The first one aims at providing an optimal diagnosis tree, whose branches correspond to sequences of tests to be applied in specific instantiated situations. In this case, the optimality criterion applies to the diagnosis tree as a whole rather than to each particular test sequence.
- The second is driven by a local optimization view and aims at providing the best next test, given a current situation. In this case, the optimality criterion applies to one test and no diagnosis tree is ever built.

The first approach was tested previously [5][6] and suffers from several drawbacks, the most important being that it does not give any flexibility to the garage mechanic. Indeed, there is one and only one test sequence corresponding to a give sequence of measurements performed by the garage mechanic. Hence, if for undetermined reasons, the garage mechanic dislikes the proposed next test, the system is unable to propose an alternative test. Hence in our approach, we follow the second point of view.

IV Work progress

During this last year our work focalised on the development of a software prototype to validate the approach. The automotive system which has been chosen as application case is "the rear window wiper system". The architecture of the prototype is separated into two main modules: the *MBR Authoring Module* and the *Test Sequencing Module* (see Figure 1*).*

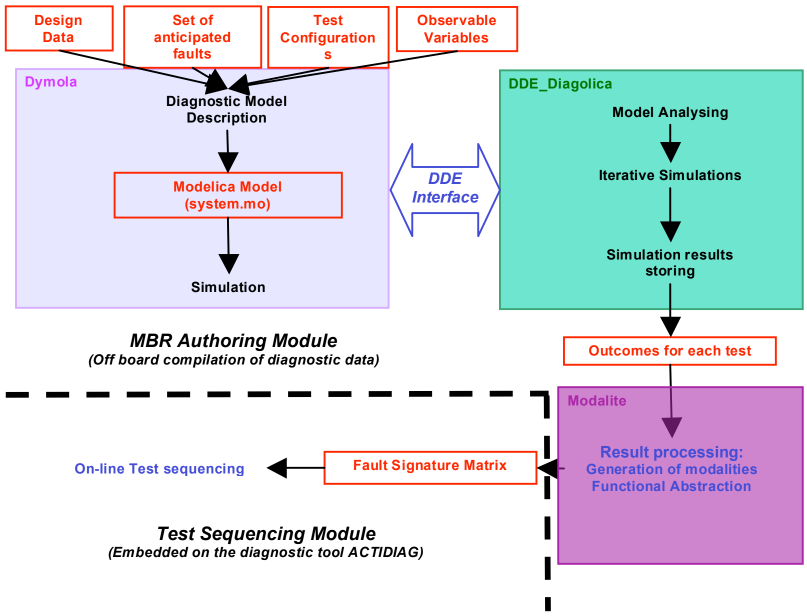

Figure 1 : Architecture of the application

IV.1 MBR Authoring Module

The task of this module is to perform the prediction step of the test sequencing problem, so it aims at generating automatically the fault signature matrix from the design data. Such tool is to be used by a human expert whose role is to describe the behaviour and structure of the system, the set of observable variables and the set of test configurations. Three sub-modules are involved:

- *Dymola* is a commercial Multi-Engineering Modelling and Simulation tool developed by Dynasim. The models are described with the Modelica language which is an object-oriented modelling language designed to allow convenient, component-oriented modelling of complex physical and hybrid systems. A generic diagnosis elementary component library has been implemented to allow the expert to describe the systems he wants do diagnose.
- *DDE_Diagolica* aims at parsing the Modelica models, launching simulation iteratively and storing each simulation result in a test matrix. One simulation is made for each fault and each configuration of the system. This application communicates with Dymola through a Dynamic Data Exchange (DDE) Interface.
- *Modalite* translates the test matrix into a fault signature matrix with modalities. The set of modalities is the set of possible outcomes for one test. To build modalities the signals are compared to each other using a Dynamic Time Warping algorithm. The other role of this sub-module is to generate the functional level tests, by abstracting signals into sequences of episodes. The abstraction algorithms are under development.

IV.2 Test sequencing module

This module is to be embedded in the diagnosis tool of the garage mechanic. A best next test selection algorithm has been implemented using the Shannon's information gain criterion given by Équation 1. $p(f_i)$ is the probability of the current probability of a fault f_i. C_j^{dyn} is the dynamic cost of a test S_j.

$$H(S_j) = -\sum_{i=0}^{N_f} p(f_i)\log(p(f_i))$$

$$Best\_next\_test = \max_j \left(\frac{H(S_j)}{C_j^{dyn}} \right)$$

Équation 1

This approach has been tested on the real system for open-circuit faults. The tests which have been made show that functional observations are very useful during the fault localisation phase as they significantly reduce the tests sequence length and cost.

IV.3 Perspectives

There are three points that I have to develop until the end of my thesis:

- To implement algorithms for the qualitative abstraction of signals.
- To evaluate the performance of the method by comparing our test sequencing algorithm with other algorithms or criteria. We are currently developing the AO* algorithm to generate fault trees like it is done in [5] and [6]. We are even studying the possibility to construct algorithms which would rather estimate the next best test sequence than the next best test.

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