

Vehicle Diagnostics Method by Anomaly Detection and Fault Identification Software

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ABSTRACT

A new approach is proposed for fault detection. It builds on using the relationships between sensor values on vehicles to detect deviating sensor readings and trends in the system performance. However, in contrast to previous approaches based on such sensor relations, our approach uses a fleet of vehicles to define the normal conditions and relations. The relationships between the sensors are also determined automatically in a self-organized way on each vehicle, i.e. no off-line modeling is required. The proposed method is the first step in a remote diagnostics and maintenance service where error detection is done automatically, followed by a download of special purpose diagnostics software for the particular subsystem where the possible fault was detected.

INTRODUCTION

Vehicle owners and fleet operators want to gain as much as possible from their assets without spending much on maintenance. Their prime goal is to operate and dispatch the vehicles optimally and the best vehicle is the reliable vehicle that always is available and delivers but costs very little to support. A vehicle that unexpectedly stops or breaks down can be very costly for the operator. Optimal management for maximizing the vehicle up-time is therefore an important factor for successful fleet

operation. However, to achieve this one must have low-cost methods for, more or less, continuous monitoring of the health status of each vehicle. This is because the maintenance schedule and predictions of remaining time to failure need to be based on vehicle health status. Also, there need to be methods that can run on-board the vehicle to detect potential faults and provide the workshop with hints (or the full solution) on the root cause of a problem, to minimize the down-time in the workshop. Such a system will not only help in optimizing the maintenance intervals and shorten the visits in the workshops, the spare parts handling can also be improved and the need for keeping different spare parts in stock can be decreased. Equipped with such a service system (i.e. a corrective maintenance system) the different stake holders of a vehicle or a fleet of vehicles will find themselves spending more time and effort on their core business.

Service planning is traditionally based on mileage or time since last service. Models for health status estimation or remaining life time is traditionally done by running a large number of experiments (before the component or system goes into production) and then derive characteristics for remaining time to failure. The drawbacks are many

- The procedure is intensive in terms of personnel and laboratory time.
- Different vehicle variants require new experiments (new models).

- Only the most important faults can be included, it is not feasible to produce software for all possible faults.

Moreover, problems that originate in poor quality of individual parts from suppliers (subcontractors) are difficult to include. Ideally error detection and diagnostics software effort should be spent on only those faults that actually occur, which requires an omniscient system with the ability to predict into the future. However, we can try to come close to such an omniscient system by developing a system that continuously monitors the data transmitted over the data buses in the vehicles, looking for anything that behaves out of the ordinary (where “ordinary” is defined as “on similar vehicles under normal operation”).

MOTIVATION

More than 50% of the vehicle software is related to diagnostic functionality and it is estimated that 16 hours per vehicle and year is down-time due to maintenance and repair [1]. Vehicle complexity is increasing, with the introduction more electronics and services, and the diagnostics is therefore becoming more difficult. Customer service surveys identify “cost of repair” and “frequency of return visits to the dealer for the same issue” as the most important factors for dissatisfaction [2]. This increase of complexity of the vehicles requires better tools for finding the root problem. However, the vehicle complexity itself is not the only problem. The number of variants of vehicles from the same manufacturer increases, which makes it very costly to produce diagnostics functionality. Moreover, the usage of the vehicles can differ a lot between vehicles, which means that different systems can deteriorate at different rates for different vehicles. By adapting the vehicles to where and how the vehicles are used the service planning can be more accurate and the vehicle owner get a vehicle that is adapted to the specific needs for the specific case [3].

Many commercial vehicle manufacturers offer different levels of service contracts to their customers [4]. These service contracts enable the vehicle owners to get a fixed price on different level of service, in order to have a better cost control of the service costs. For the manufacturer (or others that might offer these kinds of service contracts) it is important to have a comprehensive overview of the vehicles’ system health status continuously, so that their costs can be minimized.

It is not today possible to do diagnostics with fault identification on-board vehicles for most systems due to low on-board computational capacity (a full subsystem diagnostic may even be difficult to run in real time off-board). A method must be developed that only requires limited on-board computational power to find where a more extensive diagnostic function should be applied, pinpointing the faulty subsystem so well that it is feasible to download a diagnostics software that can attempt a

directed fault search on-board. The proposed method in this paper enables remote (onboard) diagnostics through anomaly detection of the different subsystems.

RELATED WORK

The approach we propose is based on exploiting relations between sensor values on the vehicle to detect anomalous behavior. This has been done previously and successfully in the context of detecting faults and predicting maintenance needs for process plants, see e.g. [5] for an overview of this field, using different modeling methods. However, in contrast to what has been done earlier, we propose to do the modeling on-board the vehicles in a self-organized way and transfer the resulting models from the vehicles to an off-board “back office” analysis. Previous approaches require supervised modeling of each individual system and a fleet wide approach has even been considered unfeasible. A related approach that also transfers models between vehicles and “back office” is found in [6] but without an unsupervised relation finder (the variables observed are defined beforehand).

MAINTENANCE STRATEGIES

The major different maintenance concepts are

- **Corrective Maintenance** - Maintenance is performed when a fault has occurred.
- **Preventive Maintenance** - Maintenance is performed on predefined intervals, such as time, mileage etc.
- **Predictive Maintenance** - Maintenance is performed based on vehicle status/condition and predicted remaining life time for components.

In this paper we propose a method intended to be used for a predictive maintenance system.

Diagnostics is just one part of improving service and maintenance. The users and owners requires among other issues:

- Up-time
- Fast fault tracing at work-shop
- No waiting for spare parts
- Service when needed
- Only planned services and repairs

Maintenance planning tools are developed by the different vehicle manufactures. These tools help the vehicle owners to plan their services to suite their needs. Traditionally the service planning has been based on data that is derived when the vehicle is bought i.e. model and area where the vehicle is used. Service planning can also depend on how the owner plans to use the vehicle.

DIAGNOSTIC IN THE AUTOMOTIVE INDUSTRY

Diagnostics in the automotive industry is a broad subject with many different approaches. The strategy that is chosen for implementation depends on e.g. legislation of the particular system (emission related systems typically have higher diagnostic requirements) and complexity of the system. The methods that are used today can be summarized as

- **Model Based** - A (physical) model is compared with signals from the real system to detect deviations. The model is tuned from observed data (in the laboratory or during test driving).
- **Data Driven** - A “black box” model where no understanding of the physical process is used. The model is derived from observed data (in the laboratory or during test driving).

A more detailed description of these strategies can be found in [7–11]. The approach presented in this paper belongs to the data driven category. In essence, we do not require any prior understanding of the studied subsystem (but it can help) and take a “data mining” approach when looking for interesting relationships between sensor values.

ON-BOARD DIAGNOSTICS AND ERROR DETECTION

TODAY - Today it is common that the diagnostic on the vehicle is limited to shortcuts, disconnected wires or other quite simple faults (this does not apply to safety critical systems or on legally required diagnostic functions). This means that there are no functions to detect intermittent faults or the deterioration of parts.

If there is a fault that can lead to secondary faults it is possible to downgrade the functionality, i.e. if the compartment temperature sensor that controls the vehicle climate control system is faulty and shows an extremely high value and a diagnostic trouble code (DTC) is set then a default value is used that limits the functionality of the vehicle's climate control system.

The diagnostic fault codes are used to find the root cause when the vehicle is at the workshop. Hence, when the vehicle enters the work shop the technician connects a special service tool to the vehicle to see if there are any relevant fault codes that can be used on the vehicle, otherwise the technician has to rely on comments from the driver (some vehicle manufacturers enable DTC readout on the instrument cluster). A service manual gives information about possible faults based on triggered fault codes. In many cases is the driver unable to give a clear and comprehensive description of the fault or dysfunction to aid the technician in the search for the root cause of the problem. The information downloaded from the vehicle is therefore very important. Multiple faults or multiple fault codes make it more difficult to find the root cause of the problem. The worst case scenario is when the technician replaces components in a

sequential order based on the fault codes. This usually means that fully functional components are replaced (just because there was a fault code related to the component) to find the root cause, which costs technician time and results in excessive discarding of parts.

MODEL BASED DIAGNOSTICS - MBD

The basic idea is to make a model that describes a system on the vehicle and feed the model with the same signal values that are used on the real system. The output from the model is compared with the measurable output from the vehicle system; the deviation gives an indication of how well the model describes the real system. If there is a big difference between the two outputs then there is an indication of a faulty system. MBD can be applied on different levels in the information chain [11]

- Sensor signal level
- Component level
- System level
- Control system level

PHYSICAL MODEL - Model based diagnostics can be based on qualitative models or on quantitative models. Physical models of vehicle systems are often used during development. During vehicle development many models are made to simulate the behavior of different systems on the vehicle, these models can be adapted for diagnostic purposes [1]. Physical models suits systems with well defined function and component functionality. A con with physical models is that it might require high computational effort. The models can be simplified by i.e. linearization with the risk for false alarms. One have to remember that the model might not work equally good in different working points hence the residual have to be dynamic dependent on the actual working point.

With physical models it is possible to develop models for each component before any system is made, by simulations of combined models of components in a system it is possible to start develop the diagnostic functionality in an early stage in the development process. If all components are standard components and are possible to model then it is possible to build model libraries of all the different components. Not all component combinations can be diagnosed through a diagnostic model library. A new model for some combined system has to be developed in these cases.

DATA BASED DIAGNOSTICS (DBD)

Data based diagnostics is based on pure data, from the vehicle or other sources such as environmental conditions. Physical understanding is not needed (but always good) for building models. Since the models are made on data from the actual system. This means that it is not possible to build models before any hardware is made to test on.