

Remote Diagnosis, Maintenance and Prognosis for Advanced Driver Assistance Systems Using Machine Learning Algorithms

Mostafa Anwar Taie
iSAQB, Nile University

Eman Magdy Moawad, Mohammed Diab, and Mohamed ElHelw
Nile University

ABSTRACT

New challenges and complexities are continuously increasing in advanced driver assistance systems (ADAS) development (e.g. active safety, driver assistant and autonomous vehicle systems). Therefore, the health management of ADAS' components needs special improvements. Since software contribution in ADAS' development is increasing significantly, remote diagnosis and maintenance for ADAS become more important. Furthermore, it is highly recommended to predict the remaining useful life (RUL) for the prognosis of ADAS' safety critical components; e.g. (Ultrasonic, Cameras, Radar, LIDAR). This paper presents a remote diagnosis, maintenance and prognosis (RDMP) framework for ADAS, which can be used during development phase and mainly after production. An overview of RDMP framework's elements is explained to demonstrate how/when this framework is connected to database servers and remote analysis servers. Moreover, Sensors fusion is used in RDMP to detect some sensor failures and even to predict their RUL. Additionally, some well-known machine learning algorithms (MLA) are used to predict RUL of ADAS' components, and different types of input attributes to these MLA are proposed for some basic ADAS' components. MLA use training data set, which shall be constructed ideally from actual records reported remotely by RDMP (Prognosis Analysis and Self-Learning System). However, initial dataset before production of the vehicle can be created from ADAS laboratory tests (e.g. Assessments on test tracks), ADAS simulation and theoretical analytical methods. Also, experiments of using the proposed RDMP in some ADAS' components (Sensor fusion and Braking system as ADAS actuator) are presented. Summary, conclusion with proven results and future work are explained.

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INTRODUCTION

Nowadays, automotive technologies become more and more complex than before and the rationale behind these complexities is to bring to the world more safety, luxury and less time wasting. One of the most effective systems that should help the automotive carmakers to guarantee these three axes is advanced driver assistance systems (ADAS).

The Importance of ADAS in Modern Automotive

The driving assistance systems was relatively less complex in the past, as it was restricted on simple cruise control, parking assistant element and blind spot detection systems, but today these systems become more complicated due to the demand of having a more reliable and interactive systems for safer roads and more luxurious driving such as ADAS.

ADAS Applications could be road collision avoidance based on RADAR systems and/or Laser scanners, automatic parking systems based on surrounding cameras and/or laser scanner. These systems

will become more interactive and effective in decision making of the driver and they will be the only decision maker in case of autonomous driving vehicles.

Furthermore, new challenges and complexities are continuously increasing in development of ADAS (e.g. active safety, driver assistant and autonomous vehicle systems). Currently, ADAS are massively introduced and implemented into new vehicle generations, and many of them also contribute with active safety functionality and offering a high potential in decreasing road accidents.

The Growing Importance for RDMP in Modern and Future Automotive

Remote Vehicle Diagnostics is the ability to access the vehicle's performance parameters and trouble codes in case of malfunction using a wireless network, and provide necessary support services. Vehicle capable of evaluating its own health state and making (or assisting the

crew in making) decisions with respect to its system health evolution over time will be able to go further and accomplish more mission objectives than a vehicle fully dependent on human control.

Remote diagnosis, maintenance and prognosis (RDMP) systems are widely deployed in the prognostics and system health management of spacecraft in-orbit and it is applied to monitor spacecraft's performance, detect faults, identify the root cause of the fault, and predict the remaining useful life (RUL). Some trials are recently introduced in automotive domain [8].

Due to the growing complexities, criticality and importance of intelligent systems in automotive, the ability of the entire system to define its own faults and predict its potential failures is one of the most vital aspects that we need to improve and develop along with the ADAS.

As the society will rely more on ADAS, it should trustworthy and accurately knowing the RUL of their components. The presence of stable and mature RDMP framework associated with ADAS will maintain this trust.

Discusses the Importance and Motivation behind the Work

ADAS and especially Autonomous Vehicles are going to encounter a whole new set of concerns. Therefore, there will be a future concerns about what will happen if part of the system unexpectedly failed or has malfunction. For example, if sensors, which are the eye of the autonomous vehicle to see the surrounding environment, are unexpectedly not working. Prognostics for ADAS sub-systems and critical components will help a lot to avoid potential risks of those systems. Because, currently all the focus is to consider the active safety of those systems without considering the RUL of ADAS subsystems, the diagnosis of ADAS sub-system failures and the remote maintenance of those Autonomous vehicles. This is the main concern of this research.

To do the prognosis such complex systems with too many parameters impacting the prediction, the tradition analytical methods like what was done in [9] will not help. This research proposes to use machine learning algorithms (MLA) [5], [6] to build a training data and learn from it to be able to predict the RUL of ADAS' sub-systems. The goal of this research is to define a framework for RDMP of the ADAS based on machine learning algorithms.

Literature review of Prognostics and Health Management (PHM)

GM entry into prognostics for conventional passenger cars is focused on the battery, starter, and fuel pump, because these are the key components that must be healthy for the car to start. The "positive" nature of the prognostics takes the Vehicle Health Report a giant step past what many motorists consider a sales pitch for oil changes and similar maintenance items [1]. The main work of GM is about the remote prognosis via 4G for cloud analysis. Moreover, NASA has a significant work [9] in prognostics topic. However, it is specific to space research and do not consider the complexities of the ADAS in

automotive, which deal with many advanced systems and many or millions of users. For example, a previous work [9] studies the battery prognosis problem and in an analytical way and use only one parameter (voltage) to predict the RUL of the battery. However, in automotive it is totally different story, as we have to consider driving profile, efficiency of the charging system, number of years since productions etc. Our research tries to overcome automotive concerns in the prognosis of ADAS with help of MLA.

Another literature [2] state that diagnostic routines implemented on individual components cannot adequately identify the true cause of anomalous behavior because their view is restricted to component-local information. A growing trend in diagnostics research for these systems is to use system-level approaches to diagnose anomalous behavior and provide a consistent, global view of the system's health.

In [3], a Prognostics-enhanced Automated Contingency Management (or ACM+P) paradigm is introduced based on both current health state (diagnosis) and future health state estimates (prognosis) for advanced autonomous systems. Including prognostics in ACM system allows not only fault accommodation, but also fault mitigation via proper control actions based on short term prognosis, and moreover, the establishment of a long term operational plan that optimizes the utility of the entire system based on long term prognostics. Nevertheless, this method is specific and more suitable to Unmanned Aerial Vehicle (UAV).

Outline of the Paper

In the following sections, the health management of ADAS' components will be discussed including the failure indicators for different ADAS subsystems. Then, the proposed RDMP architecture will be explained.

After this section, the creation of feature vectors for the ADAS subsystems and how different ML algorithms should be applied will be illustrated in the section of prognosis analysis and self-learning. The proposed RDMP based on the selected ML algorithm will be defined in the next section.

The fourth section will show the experiment and simulation results of the proposed RDMP framework. The research summary will be concluded in the last section of the paper.

HEALTH MANAGEMENT OF ADAS' COMPONENTS

As discussed in the introduction, the importance of ADAS becomes more important and critical over the time. Accordingly, RDMP framework for ADAS shall focus on the failure indicators of different subsystems in ADAS. The presence of failure indicators does not mean that the system fall in failure state; but it means that this system is expected to fail in the future after a while or after a certain number of operations.

Failure Indicators for Prognosis of ADAS' Sensors (Cameras, Ultrasonic, Radars, LIDARS, etc ...)

ADAS use different types of sensors (Cameras, Ultrasonic, Radars, LIDARS, etc...). Each sensor has its own failure indicator. In the below sub-sections, the factors/attributes, that are most likely suitable to be utilized by the RDMP framework, will be proposed in order to help in the RUL and failures prediction of some ADAS' sensors.

Cameras

Most of the automotive digital imaging sensors are either based on CCD or CMOS technologies [10]. According to the ISO 13406-2, there are 3 types of failure symptoms that could be considered as a warning for potential image sensor failure in the future. These types of symptoms are the presence of "dead-pixels", "hot-pixels" or "stuck-pixels". Along with the existence of these symptoms the RDMP framework should also take into account the number of kilometers driven and accumulative time of cameras operation in each record.

Indeed, these factors are not only factors for image sensor failure, other factors could be found and added to the feature vector of the potential camera failure such as, the physical impact of the external environmental conditions on the cameras lenses (the effect of sands and stones while driving), and the life span of the electronic camera driver.

Ultrasonic Sensors

Actually, there are no straight forward failure factors that could be considered by the RDMP framework in calculating the RUL of the ultrasonic sensors. Nevertheless, the RDMP can rely on some measurements that may indicate the RUL of ultrasonic sensors. These measurements are the readings of the sensors in calibration areas existing in the maintenance centers, or the drifts between sensors readings lying on the same physical areas (near from each other). Moreover, it is highly recommended to include the overall number or time of operations of ultrasonic sensors, defined by their manufacturer (if available), in the initial feature vector.

Failure Indicators for Prognosis of ADAS' Actuators

Braking Systems

The braking system [4] is very critical part of ADAS; and based on its response, collisions could be avoided. Most of the braking system elements are mechanical parts; accordingly, the durability of its components is highly impacted by the environmental factors surrounding the vehicle and the driver behavior.

The measurements of the following parameters could be useful in determining RUL feature vector of the braking system such as "Number of full applied brakes per KM", "Number of partially applied brakes per KM", "Min De-acceleration per KM" and "Max De-acceleration per KM", "Average External Temperature per KM" [4], "Maximum Steering angle at applied brake per KM", "Accumulative KMs since zero time", and "Relative Usage Days since zero time".

Of course, the effectiveness of RDMP based on MLA will depend on how feature vector parameters/attributes will be selected, weighted and this is the responsibility of the manufacturer system experts. The better attributes selected, the better RUL prediction obtained.

Failure Indicators for Prognosis of ADAS Complete System Behavior

The RDMP shall analyze the collected data from the vehicle sensors and measure the response of the actuators to detect the potential failures in the overall ADAS system behavior (black box scope), such as the overall system inappropriate response time for collision avoidance in different situations (response time evaluation of Automatic Emergency Braking system (AEB) using RDMP Embedded software). There are two factors major factors that impact the evaluation of those systems: environmental conditions (such as day, night, rainy, the presence of fog, etc...) and traffic factors (such as vehicle location, the presence of traffic jam, roads capacity, etc...).

PROGNOSIS ANALYSIS AND SELF-LEARNING SYSTEM

The complexities in ADAS systems will be very hard to be handled via analytical methods like what was done in [9] to prognosis the battery via only one parameter (e.g. voltage of the battery). MLA are the typical solution for predicting complex systems with many complex parameters (attributes/features to MLA classifiers).

This research proposes to use RDMP-Server as part of the RDMP framework to received records from vehicles equipped with ADAS. On the other hand, vehicles equipped with ADAS shall contain embedded software component (RDMP-Embedded) for reporting some parameters (only if agreed by the vehicle's driver to respect privacy regulations) to OEM's server to be used for remote prognosis.

Table 1. Vehicles Profile: Its ID, ADAS Components ID, Zero time (actual time at which this component is installed or maintained) and ADAS' Components RUL in KM

Vehicle ID	ADAS Component ID	Zero Time	RUL (Km)
1	1	12:00 15.10.2015	20,000
	2	12:00 15.10.2015	30,000
2	1	10:00 14.10.2015	5,000
	2	10:00 14.10.2015	10,000

RDMP-Embedded component shall be able to communicate via the vehicle network (e.g. FlexRay) to vehicle's telematics unit, which will act as a gateway to send the OBE reports via cloud (e.g. using 3G/4G communication) to the OEM's servers, like GM remote prognosis solution via 4G [1]. Moreover, RDMP-Server shall receive the data and record it in database, as indicated in Table 1 for vehicle's profile and Table 2 for detailed database records.