“Forecast” - adaptive forecast diagnostic intelligent system for vehicles

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Abstract. The article contains general information about promising vehicle diagnostic systems. Existing diagnostic systems, including those built into modern vehicles (MV), are not able to predict the moment of failure of components and assemblies, but only state the fact of a malfunction. To diagnose the current state and predict the residual life of the vehicle in motion mode, a mathematical model, based on machine learning technologies and data from standard additional sensors and MV detectors, is suggested. Using this approach will make it possible to forecast the defect before its actual occurrence.

1. Introduction

For autonomous transport and connected vehicles, the diagnosis of a vehicle’s technical condition is a basic safety standard.* The issue of determining the mechanical failure in unmanned vehicles is extremely relevant due to the lack of driver who can assess uncharacteristic noises or external vibrations. Errors received from vehicle tires are not sufficiently informative when assessing the current state of MV and do not predict breakdowns or faults. An expanded self-diagnosis system should be laid at the stage of design of autonomous vehicles. In the process of exploitation the data from sensors and reliability monitoring systems will be processed on board MV and transferred further to the ITS - intelligent transport system, as well as to the servers of owners and manufacturers. (* according to the research of the European Commission, more details further in the article).

2. Main part

Almost all modern cars are modified with a variety of full-time detecting devices and sensors, fixing faults and operation errors of some units by electrical parameters and fixing “extreme” system states in codes. Error icons appear on the vehicle dashboard when the system detects a fault. If the driver notices an error indicator or an incorrect operation of certain unites or systems and needs to find out the technical condition of the vehicle, some specialized diagnostics is carried out.

To identify the technical problem computer diagnostics of the vehicle is carried out by a certified technical specialist: a scanner with software is connected to the on-board systems through special diagnostic connectors (CAN bus data) which reads all the codes transmitted by the car about possible malfunctions on the main units. Error codes are currently vendor-specific, set by OEM and available for reading and monitoring on a limited list of codes. The received codes are decrypted by specialists using special programs and on the basis of the received data a conclusion about the presence of certain failures or malfunctions is made. On-board data consists of thousands of signals from sensors and ECUs that get transmitted through the CAN network.
They are sent repeatedly with a certain frequency and form continuous data streams that can be used both for driving a vehicle and for signaling the status of various components of the vehicle. Research on monitoring and signal analysis of standard sensors is carried out by vehicle manufactures and so far continuous registration on board has been limited to the vehicles during testing periods when they are developing new models or modernized equipment. These systems are expensive and designed for product development.

In the automotive industry there is little research in predictive prognostics using on-board data from standard sensors. Currently, such methods either require the participation of a person for an expert assessment or the technical condition of the car is assessed by monitoring signals and comparing them with perfect process model. In the problem development review, the main approaches to the solution are formulated in the following methods: Model-Based Diagnostics (MBD) method and the Condition Based Maintenance - CBM method [1]. There are effective studies based on onboard forecasting methods:

- D'Silva carried out a complex stationary system based on a method on the formation of a cross-correlation matrix, including pairwise correlations between signals, where the Mahalanobis distance is used as an assessment scale to search for deviations and malfunctions [2]. The full correlation matrix is used to determine vehicle status. Normal workspace is determined from experimental data. The system works on board with saved normal operation models, and this was demonstrated on simulated data.
- stationary signals for finding damage were used by Vachkov [3] and Kargupta et al. [4]. Their systems consist of an onboard part that continuously monitors the vehicle and loads models into the onboard analogue of OEM monitoring systems. An autonomous system includes a database in which data models, faulty and faultless systems are stored [5]. Also, for embedded on-board systems with limited resources, methods are developed in which sudden changes in the correlation matrix are signs of wear or failure [6].

Until recently car manufacturers have not been interested in developing technologies of exploitation monitoring, but in the present, in connection with the emergence of contractual relations on the principle of “full-cycle service” related to the development of rental, commercial and autonomous vehicles, the topics of reliability forecasting are foregrounded. Commercial vehicle manufacturers have not yet released any advanced forecasting solutions to the market. There are simple preventative maintenance solutions for assessment and prediction of wear that track wear and use of brake pads, clutches, and similar wear equipment. All of them are based on data streams that are aggregated on board and transmitted to a remote office. Mercedes and MAN, among other things, offer to the customers direct remote monitoring and preventative maintenance recommendation solutions. Volvo for commercial vehicles includes forecasting systems offered with maintenance contracts. Volkswagen, BMW [7] and GM [8] have methods for predicting future service needs based on telematics solutions and on-board data. VW and BMW offer preventative maintenance as a maintenance solution for the owner, and GM publishes recommended repairs through the OnStar portal.

Developed embedded on-board solutions have unlimited access to real-time data streams. This provides fast detection since the detection algorithms are located close to the data source. On-board solutions usually have limited computing and storage capabilities, since the hardware must be automotive-grade, for example, resistant to water, shock and electromagnetic interference, as well as inexpensive. Typically, automotive electronics are usually two to three generations behind the consumer market.

The conceptual model which is being developed by the authors is planned to be used in terms of the implementation of remote diagnostics services of the intelligent transport system (ITS) for the connected transport. This service is supposed to be mandatory for the purpose of ensuring exploitation of connected and autonomous vehicles. The service will guarantee feedback on the exploitation of the full product life cycle to manufacturers.
The direction of the ongoing research coincides with the direction of work within the framework of the European Commission C-ITS, according to the statement of which (Fig. 1) (Cooperative Intelligent Transport System Delegated Act), adopted and agreed by the key stakeholders from the automotive, motorcycle, agricultural, and telecommunications industries; international technical organizations are developing integrated solutions for the priority of the road safety.

![Figure 1. Scheme of the interaction of International Technical organizations, which are making standards for the development of ITS.](image)

The 3GPP international consortium develops technical specifications and technical reports in the field of network technologies in mobile systems together with the European Telecommunications Standardization Institute (ETSI) which transfers the worked out documentation on communication standards and ITS services to the ITU (International Telecommunication Union), which is a specialized institution within the United Nations (UN). It is responsible for issues related to information and communication technology. ITU transfers data to the United Sustainable Nations Development Group - the United Nations development group, which approves international standards at the ISO site.

In international concepts of the ITS development, special attention is paid to the issues of diagnostics and monitoring of connected and autonomous vehicle technical condition. The 3GPP international consortium is developing a standard for connected vehicles *3GPP 22.885 p. 5.27 – “Remote diagnosis and just in time repair notification”*, which provides for the installation on the connected vehicle devices with a hardware-software complex that supports interaction C-V2X, (Vehicle-to-everything) and collects diagnostic data from sensors inside the vehicle.
Diagnosis of the technical condition of the vehicle is solved by developing a prognostic model for monitoring electrical, mechanical and hydraulic failures of the vehicle components and assemblies.

![The System of Database Interconnection:]

- **FMEA**: Failure Mode and Effects Analysis
- **3GPP**: 3rd Generation Partnership Project

**Figure 2.** The relationship of databases in the system under development.

The novelty of the idea and its advantages lie in the creation of a model for processing data obtained from various monitoring and diagnostic systems, using a neural network to predict the operation time before the failure of a unit, taking into account the optimal load mode.

Figure 2 shows the relationship between the databases of the described system, which may be applicable for various vehicles. Information is collected as follows: additional sensors are installed on the vehicle, the data received from them together with the data from CAN-BUS and theoretical and statistical results are received and processed on the onboard hardware-software complex by a neural network. After this, the initial data conversion and predictive analysis send it to a remote ITS server with hardware-software complex. The mathematical models used in the analytical process rank incoming data by the integrated indicators for assessing the residual life of the diagnosed units. The analytical system of the ITS in the process of exploitation, taking into account current loads impact assessment and modeling previous and future operating parameters, creates a virtual dynamic operational model for a particular vehicle.

Information from sensors and detectors, based on vibration measurements, acoustic emission and generated heat intensity, determines the technical condition of the hydraulic or mechanical units of the vehicle and is used for the construction of a virtual mathematical model on the ITS. The used complex acoustic emission energy parameter adequately estimates the change in the friction coefficient in the kinematic pair. The complex energy parameter of acoustic emission, in Fig. 3 - parameter D, is calculated on the base of the analysis of a working friction pair acoustic emission signals at ultrasonic frequencies of 20-300 KHz, with ranges from 10 to 10,000 rpm. The sources of acoustic-emission signal formation in the ultrasonic frequency range are elastic deformation waves formed by the dissipation of fracture energy in the structure of materials [9]. Figure 3 shows the confirmed results obtained with the help of an acoustic emission analyzer in experimental modeling of a friction pair.

The transition to the evaluation of the signal by acoustic emission method makes it possible to evaluate the magnitude and nature of the change in energy dissipation that occurs when objects interact in the ultra-acoustic range, to obtain information on friction in the unit and to diagnose this process with
an assessment of the condition of the friction pair, attachment quality, lubrication nature and conditions and other parameters in contact. So, when the level of the acoustic emission signal in the friction unit is changing, it is possible to evaluate lubrication quality of the controlled unit. Constant monitoring of the quality of the lubricant will reduce the wear rate and development of defects.

To assess energy losses with the acoustic emission method a diagnostic device is used: it fixes the integral indicator - complex energy parameter of acoustic emission. According to the previous studies’ results, the RF patent No. 2427815 - G01M13 / 02 - transmission mechanisms test, "Method for the diagnosis of mechanical transmissions" is registered [10].

![Graph](image)

**Figure 3.** The ratio of the complex energy parameter $D$ to the force in the simulated kinematic pair, $N$ force on the contact spot.

Calculation methods have objectively established the proportionality of the integral indicator of the acoustic emission sensor signal and the friction coefficient, both for gears and bearings. It is this area that has expanded the existing non-destructive testing methods capabilities, which will allow solving practical problems of mechanism condition monitoring and forecast, rationally distributing forces and means during repair and inspection of vehicle technical condition. Traditional approach resource forecasting is based on the design and construction parameters of unit elements and failure statistics and does not give a real result on operational reliability. It is proposed to change the approach to data processing methods using machine learning. In this case, element failures are considered as some abstract random events of the multifactor process, and the diverse physical conditions of products are reduced to two states: serviceability and malfunction. Prediction problems must be considered with errors in the initial and boundary conditions even when the non-stationary process can be considered as a strictly deterministic process, that is, its outcome is completely determined by the algorithm, the values of the input variables and the initial state of the system. Based on mathematical models of vehicle components and the dependences of sensor and detector data changes, when compared with operating conditions and CAN data, creation of an analytical complex applicable to a wide range of vehicles is proposed.

The complexity of the implementation of the diagnostic complex is not only in the necessity to take into account the operating conditions of a particular vehicle, but also in the need to carry out maintenance in accordance with these conditions. A modern service system must interconnect individual vehicle technical condition continuous monitoring data, planning of their operation by a trucking company and readiness of the service department to fulfill the required vehicle maintenance and repair works.

A general problem that the operating organization is faced with when using schedules of service maintenance and planned replacements of units is the fulfillment of an inappropriate amount of asset maintenance. Since calendar-based maintenance does not take into account the asset’s performance, the
frequency of maintenance works can often be either too high or too low. These problems can be prevented by optimizing and improving preventative maintenance programs.

The system of preventive diagnostics based on artificial intelligence will make it possible in future to abandon the system of scheduled preventive repairs and switch to maintenance by actual condition [11], experts estimate that it will reduce maintenance costs by 75%, the number of services by more than 50% and the number of failures by 70% in the first year of operation.

3. Conclusions
Advantages of maintenance according to the proposed system:
- The system can be applied in various industries and is adaptable;
- Registration of signs of failure signs and analysis of their variations is performed. Assessment of failure probability of both the system as a whole and its individual units;
- Failures of units are transferred from the category of suddenness to the category of predictability, due to early detection and notification of personnel about a developing malfunction;
- Spare parts logistics is being optimized - timely order and delivery.

The expected economic effect from the introduction of the proposed preventive diagnostics system is possible due to reduction of downtime caused by malfunctions, maintenance and repair costs. The proposed system solves the problems of insufficient competence of employees in assessing the technical condition, and will also help maintain the working condition of aging equipment in a limited budget.

Realized analogs in the field of objective resource forecasting do not exist. The advantage is the prospect of integration into the ITS (Intelligent Transport System), and the creation of a predictive service for any type of vehicle, and most importantly this is the only way to diagnose autonomous vehicles in the field and on the road.

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