Interactive (Intelligent) Integrated System for the Road Vehicles' Diagnostics

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Abstract. Existing organization schemes of the vehicles' diagnostics are considered in the article and interactive complex vehicle diagnostic system is proposed on the basis of this analysis. The diagnostic algorithm is presented. To implement it, the intelligent diagnostic system based on monitoring the residual life of the vehicle's units and assemblies is developed. It consists of Server of diagnostics, Autonomous information-diagnostic blocks and Display and control unit. Currently, module for collection and processing information is developed. Operational tests of the vehicles when the sensors were installed were carried out together with manufacturer "KAMAZ".

Keywords: Diagnostics · Branded service autocenter
Interactive complex vehicle diagnostic system · Sensors

1 Introduction

The sophisticated system of a modern vehicle requires regular inspection of all units and mechanisms, since the safety of the city's public transport system directly depends on the reliability and good state of the vehicles fleet [1–3]. Qualitative repair is impossible without preliminary diagnostics of the vehicle that allows revealing latent faults, determining the amount of damage (wear) and the scope of work to eliminate it.

Every year the products of automobile factories undergo significant changes, it becomes more complicated, both technically and programmatically, and requires careful preparation of manufacturing and service processes.

In order to equip production with modern equipment with precise parameters of the components' processing, to improve and finalize technological processes and to make personnel to pass specialized trainings, data analysis must be carried out based on the assessment of the market and consumers' needs and on the data obtained from the vehicles in the field (fault database).

2 Existing Methods and Means of Vehicles' Diagnostics

Nowadays vehicles are equipped with a large number of electronic control systems (ECSs) from various manufacturing companies such as BOSCH, Cummins, WABCO, Knorr-Bremse, ABIT, ZF, VOITH, Daimler, BMW [4] and others. Many individual

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applications have been developed for diagnosing vehicles' parts and components [5, 6], as well as applications that integrate an on-board computer with a driver's mobile device [7]. Diagnostics of the vehicles at service stations can be carried out only if there is a sufficient number of original test equipment from the manufacturers of ECSs. This fact complicates the diagnostic process. For example, to diagnose one vehicle specialist has to take with himself several types of cables and computers (laptops), that is inconvenient and takes a lot of time. Moreover, vehicles' systems are constantly becoming more complex and it becomes more difficult for workers to identify and repair a particular fault due to the lack of information. This also leads to an increase in maintenance time. The maintenance time and quality influence on the consumer's satisfaction with the services provided, and therefore, affects the demand [8].

There is one more problem on the part of the automotive factory. The collection of reliable statistical data on faults is also very important for the possibility of evaluating these data and finalizing the vehicle's systems, units or other components.

As one of the solutions to the problems described above, many researchers propose the use of expert failure diagnosis systems, the first of which was developed at the Massachusetts Institute of Technology in the early 1970s.

The research paper [9] is devoted to the designing of an Expert System (ES) for vehicle failure diagnosis and repair. Many factors are considered in this research such as the required time, the place and human expertise level. In addition, the ES development is accompanied by reviewing the technologies used in designing such system to conclude the best means to be followed. However, the proposed prototype is not promoted to be used as a complete application due to time and resources limitations. Thus, adopting new rules to be performed is an example of further enhancements that the system need. A survey was done by [10] for developing motocultivator fault diagnosis model. This model is based on the hybridization of Expert System (ES) and Decision Support System (DSS) in which ES outcome represents the input to the DSS.

The paper [11] presents the imperatives for an ES in developing vehicle failure detection model and the requirements of constructing successful Knowledge-Based Systems (KBS) for such model. In addition, it exhibits the adaptation of the ES in the development of Vehicle Failure and Malfunction Diagnosis Assistance System (CFMDAS). However, CFMDAS development faces many challenges such as collecting the required data for building the knowledge base and performing the inferencing.

The structure of a multi-function car-carry fault diagnosis system, and the design of vehicle status monitoring module is proposed in the study [12]. Furthermore, authors of this paper analyze the design of vehicle fault diagnosis expert knowledge base, inference machine and interpreter program. Finally, this paper discusses hardware and software design of the fault diagnosis system, and demonstrates the system's human-machine interface operating results.

On the basis of analytical review of existing developments, the methods for collecting, processing and analyzing diagnostic data, it can be concluded that in spite of a large number of researches in this area, it is necessary to develop an integrated diagnostic system based on the on-line monitoring of the residual life of vehicle units and assemblies.

3 Possible Organization Schemes of the Vehicles' Diagnostics

Automobile service enterprises mostly use the diagnostic system shown in Fig. 1.

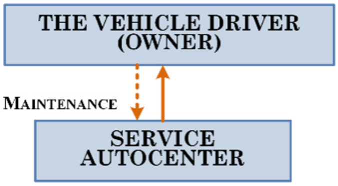

Fig. 1. The relationship between the driver (owner) of the vehicle and the service center.

Advantages:

- driver's (owner's) appeals are processed directly at the service station;
- high-quality and complete diagnostics;
- generation of detailed reports after the diagnostics;
- universal equipment for autocenters and service stations;
- low price of equipment and its annual maintenance.

Disadvantages:

- The computer complex, that is used, is limited by the list of built-in electronic control units (ECUs) and the functions included by manufacturer. There is no possibility to expand the functionality in order to meet the needs for maintenance of autonomous vehicles, that are planned to be manufactured in the next 20 years;
- The size of the equipment makes it difficult to move it and takes a long time to organize the working process;
- The lack of reliable information on each system of the vehicle from the manufacturer, that is necessary for qualified training of the service station's personnel;
- The lack of feedback from the manufacturer that is necessary for collecting statistical information on systems' (units', parts') faults to improve production and the products quality.

This type of diagnostics scheme is not provided for large-scale organization of diagnostics of the branded service autocenters.

The following system of diagnostics organization (Fig. 2) is mainly used by branded automobile service enterprises. This system includes an automotive factory, which provides technical and program support.

Advantages:

- processing of the driver's (owner's) appeals is carried out directly at the service station with the possibility of using limited technical information from the manufacturer;
- provision of the service station with limited technical information from the vehicle manufacturer (firmware of ECUs, electrical diagrams and recommendations of electronic control units manufacturers for repair work);

- resources (spare parts are provided by the vehicle manufacturer);
- vehicle manufacture's specialists provide the qualified training of the service station's personnel for the competent performance of diagnostics;
- generation of reports on the diagnostic work performed;
- compact equipment is convenient for transfer and the use during the work;
- ability to remotely connect the PC to the adapter via Bluetooth technology.

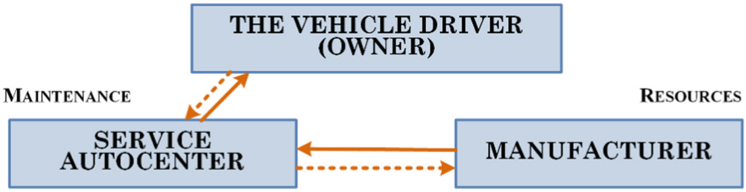

Fig. 2. The partial relationship between the driver (owner) of the vehicle, the service center and the manufacturer.

Disadvantages:

- The work is limited by only one or the list of the built-in ECUs and the functions included by manufacturer. There is no possibility to expand the functionality in order to satisfy the need for maintenance autonomous robotic vehicles;
- The lack of feedback from the manufacturer that is necessary for collecting statistical information on systems' (units', parts') faults to improve production and the products quality.
- The high price of equipment and its annual maintenance.

Nowadays almost all branded service autocenters are based on this principle of interconnection and have a large number of such equipment at their disposal, because each manufacturer of the ECUs promotes its branded products (or products with a limited number of supported control units) at a high cost. This scheme is also inconvenient for carrying out diagnostics, because the specialist servicing the vehicle have to use different types of connecting cables, adapters and software. If there are different types of electronic control units in the vehicle's configuration, the maintenance time increases.

The diagnostic system in Fig. 3 represents the complete relationship between the driver (owner) of the vehicle, the service center and the manufacturer.

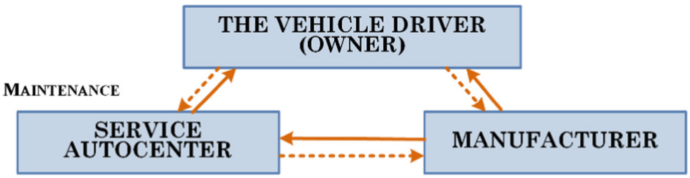

Fig. 3. The complete relationship between the driver (owner) of the vehicle, the service center and the manufacturer.

Advantages:

- processing of the driver's (owner's) appeals is carried out not only directly at the service station. This type of scheme also provides an opportunity to monitor the vehicle's condition with the help of installed onboard system operating with telematics technology;
- the possibility to develop a diagnostic equipment by the vehicle's manufacturer allows reflecting all available experience of using the ECUs installed on produced vehicles;
- vehicle manufacturer provide the qualified training of the service station's personnel for the competent performance of diagnostics;
- detailed recommendations of the fault-handling that will minimize errors during the working process at the service station and reduce the maintenance time;
- diagnostics algorithm are developed taking into account the documentation and recommendations from the ECU's and vehicle's manufacturer based on the experience of their specialists in order to create an intelligent symptomatic diagnostics;
- providing feedback to the vehicle's manufacturer for the accumulation, processing and structuring of statistical information on systems' (units', parts') faults obtained from service centers to improve the quality of products and manufacturing;
- generation of detailed reports on the diagnostic work performed;
- the possibility of creating a multi-branded equipment for diagnosing the built-in ECUs of different branded manufacturers of electronic components;
- compact equipment is convenient for transfer and the use during the work;
- the ability to remotely connect the PC to the adapter via Wi-Fi technology and to use it in the future in conjunction with a telematics system for diagnosing vehicles in the "field";
- ECUs' manufacturers provide service station with technical information on ECUs, as well as automotive manufacturers provide it with spare parts and recommendations for diagnostics.

Disadvantages:

- diagnostics of electronics is mainly carried out;
- the high price of equipment, of the further joint development of the diagnostics solution and its annual maintenance.

On the basis of this solution, a scheme of the interactive vehicle diagnostic system is proposed (Fig. 4).

The development of an interactive complex vehicle diagnostic system will help to streamline the maintenance process and it also will provide (1) a unified diagnostics tool, (2) the possibility of remote diagnostics "in the field" using the Call center, instructions, intuition and step-by-step recommendations for detecting and further elimination of faults, and (3) the ability to accumulate statistical data on damages for their subsequent processing, as well as their structuring. All this will greatly help to improve the quality and reduce the maintenance time, as well as to prevent downtime in the service autocenters.

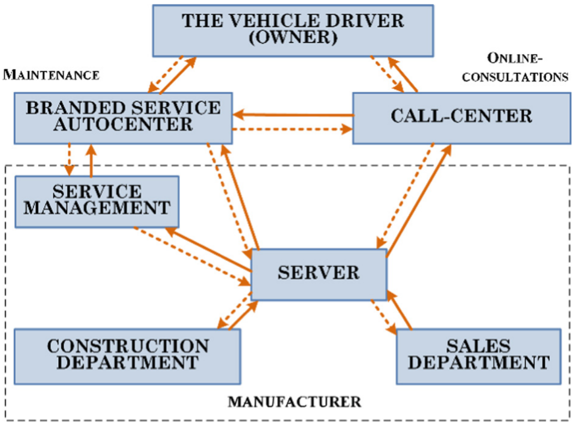

Fig. 4. The scheme of the interactive diagnostics service system.

4 The Proposed Interactive Complex Vehicle Diagnostic System

For interactive monitoring and diagnostics of the vehicle's systems, assemblies and units while performing their functions, they should be equipped with sensors and actuators that are necessary for obtaining diagnostic information and its processing in order to generate a diagnostic report. Development of the diagnostic algorithm is preceded by the analysis of statistical data on the most frequently occurring faults and failures. At the same time, the interrelation between the structural and diagnostic parameters of the vehicle is revealed (Fig. 5), where the first group consists of systems, units and nodes providing traffic safety (PTS), and the second contains the remaining functional systems (FS). Each group includes a certain number of n units and systems from the total aggregate r. The technical state of each unit (system) is characterized by some set of $i \leq N$ diagnostic parameters, where N is the total number of diagnostic parameters characterizing the state of the vehicle, its individual units and systems. Each of the i diagnostic parameters depends on the values of the corresponding k structural parameters characterizing state of the object, its individual units and systems.

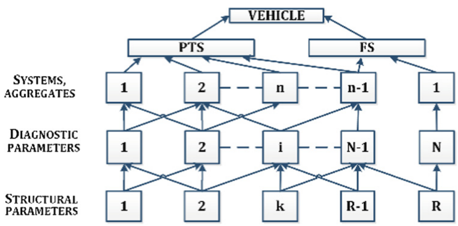

Fig. 5. Interrelation of structural and diagnostic parameters.

The diagnostic algorithm is developed in a such way that it could determine the operability of the object and localize the detected faults on the basis of the selected list of parameters and the sequence of their measurement. The depth of the fault localization is determined in each specific case by its level: replacement of a part, replacement or repair of an assembly or unit, carrying out the necessary adjusting operations. This level is determined by operational (and economic) factors, regulated reliability indicators, the requirements for ensuring the safety of the vehicles crew, maintaining environmental characteristics and performing the tasks assigned. The final stages are the development of the basic and integrated route technologies. The basis of the algorithm development is the statistical modeling problems. The vehicle's technical state is determined by the structural parameters, however, in most cases it is impossible to carry out their control without disassembly. To reach this purpose, diagnostic parameters are used. They are indirect quantities associated with structural parameters and carrying sufficient information about the technical state of the object.

When assessing the vehicle's technical condition, parameters of working processes; parameters of associated processes (vibration, noise, etc.); geometric parameters (clearances, free stroke, backlashs, misalignment, etc.) can be used as diagnostic parameters. The choice of diagnostic parameters depends on their relationship with structural parameters, as well as their compliance with the requirements of uniqueness, stability, sensitivity, information density, repairability and maintainability.

Since the implementation of the proposed concept is associated with the collection and analysis of Big Data, the most effective solution of this problem is to develop an intelligent diagnostic system based on the on-line monitoring of the residual life of the vehicle's units and aggregates (Fig. 6). The main elements of the proposed system are:

1. Central processing unit (server of diagnostics) collects, analyzes and processes information that is received through wireless communication channels from autonomous information-diagnostic units. It carries out the control and diagnostics of regime parameters and forecasting the vehicle's residual life. The central processing unit provides real-time failure identification of the vehicle's component, which are the most important from the point of view of ensuring its safe operation, and initiates the inclusion of an element that is in a good state and that performs similar functions. If it is impossible to turn on the reserve element, the central processor unit gives a command for an emergency stop of the vehicle.
2. Autonomous information-diagnostic blocks are designed for operative reception of signals from the regime parameters' sensors. They carry out a primary diagnosis, monitoring and analysis of the regime parameters. The received data is stored in the non-volatile memory of the unit. Diagnostics units transmit and receive information from the central server of the system through the communication channel. They also position the vehicle with the help of GLONASS, as well as generate control signals for actuators. Autonomous information-diagnostic blocks should be placed as close to the corresponding sensors as it is possible. Communication with various system devices and digital sensors is carried out according to a standard protocol such as LIN-interface or CAN-interface. The communication line is a shielded twisted pair. The communication line with analog sensors should also be shielded. Different types of sensors (analog, digital) are connected via appropriate converters to the

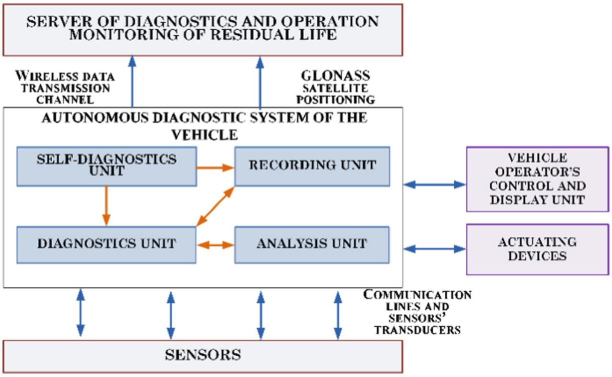

Fig. 6. Structural diagram of the diagnostic system based on monitoring the residual life of the vehicle's units and assemblies.

inputs of the autonomous-information diagnostic unit controller. The controller output circuits serve to control the actuators.

3. Display and control unit provides the transfer of the necessary diagnostic information to the driver and serves for receiving control commands from him.

Power supply of all diagnostic system's elements is carried out through the vehicle's common power bus with fuse protection. The power of the autonomous information-diagnostic unit can be connected to a power source with a backup battery.

The system has a modular structure and allows expanding it with the addition of new diagnostic units with various applications and diagnostic features.

The principle of the autonomous information-diagnostic unit operation is based on the collection, analysis and primary processing of data obtained from sensors.

To monitor the integrity and operability of all nodes of the unit the self-diagnostic unit conducts a survey of the circuit with a test signal at the beginning of operation. When the correct answer is received, the diagnostic unit is enabled. Otherwise, the self-diagnostic unit issues a corresponding signal to the control panel of the operator (driver) and the wireless channel to the central server of the system.

The procedure of the diagnostics workflow:

1. Obtaining primary information from the system's sensors. The received unprocessed information is recorded in the controller's memory;
2. The diagnostics unit performs processing of the data array by wavelet transformation methods and calculation of the mean square values of wavelet coefficients at frequencies corresponding to diagnostic purposes;
3. Record the processed results of the wavelet transformation into the controller's memory with reference to the date and time for the possible further processing;
4. Comparison of the obtained mean square values of wavelet coefficients with their nominal and limiting values stored in the diagnostic block memory.

(a) If the received spectrum is less than the nominal one, then a conclusion to continue operation is made. The procedure for collecting and processing information continues.

(b) If the current spectrum is more than the nominal one, the autonomous diagnostic unit transmits the relevant information to the diagnostic system server, which having processed the received data by the appropriate method predicts the residual life of the diagnosed vehicle units and assemblies.
(c) If the current spectrum is greater than the limiting one, the autonomous diagnostic unit gives the command for an emergency stop of the vehicle. This situation is possible, for example, if the autonomous unit is not connected to the central server of the diagnostic system for a long time.

On the basis of the forecasting results, the server either gives permission for the further operation of the vehicle, or, in the case of critical results of processing, initiates a message to the driver about the need for maintenance or emergency shutdown of the vehicle.

Currently, the proposed system is at the first stage of implementation. The data on all KAMAZ vehicles' elements and units are collected and stored in a common database in the Siemens PLM platform – Teamcenter [13], diagnostic algorithms of each element and unit are developed with the use of software ODXStudio [14] and are also added to the database of the Teamcenter. As a result, all KAMAZ branded service autocenters have the opportunity to use this resource for on-line access to information that is necessary for qualitative diagnostics of the vehicles. The next stage will be the collection, transmission and processing of data on the state of the vehicle in real time. This will become especially relevant when driverless vehicles will become a mass transport. However, in this case, the use of wireless data transmission technologies will cause new tasks related to ensuring the security of transmitted data, since interception of a signal can mean the possibility of third-party intervention to the control and monitoring processes of the vehicles. Each vehicle should be equipped by telematic on-board devices for the satellite navigation ("GLONASS" tracker) and data transmission (GSM/GPRS). Data security will be met by a microcontroller SmartMX [15] that is certified Common Criteria EAL 5+, so it protects against light attacks, invasive fault attacks, and side-channel attacks, and comes with a CRI license for improved DPA/SPA attack resistance features. It offers advanced attack resistance and high performance, with cryptographic coprocessors and ultra-low-power design. To service a range of applications, SmartMX supports proprietary operating systems as open-platform solutions such as Java and MULTOS.

5 Conclusions

The proposed interactive diagnostic system allows the branded service autocenters to implement the information interaction of the subsystems of the branded vehicles' service system, because it takes into account the integrated approach to the development of the branded service network and vehicle diagnostics.

Taking into account that the control of the vehicles' state should be continuous, it is necessary to improve the following areas: (1) development of the on-board information management systems and accompanying technological software that implements the diagnostics and the state control cycle based on the built-in operational algorithms;

(2) identification of connections between diagnostic and structural parameters of units; and (3) the establishment of mathematics relations between them.

Operational tests of the vehicles that were carried out by manufacturer “KAMAZ” (when the sensors were installed) allowed establishing functions of the vehicle’s units’ and aggregates’ state parameters. Analysis of the obtained regularities has shown that this method has significant prospects, since with adequate selection of sensors and improvement of on-board diagnostic systems, it allows to determine the wear values and predict the time of the eventual failure.

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