Protection of unmanned vehicles from component failures

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Abstract. For the transfer of road transport to unmanned driving, it is necessary to create not only technologies for automatic control of the movement of vehicles, but also technical measures to protect them from failures of components of unmanned vehicles. Such protection will ensure the development of monitoring the performance and operational properties of unmanned vehicles in combination with algorithms for the use of its results. The purpose of this work is to substantiate the methods of automation of control parameters of performance of unmanned vehicles and the construction of protective control algorithms of unmanned vehicles in the interests of technical operation. A new method of automatic control of parameters dependent on the technical condition, modes and operating conditions of vehicles is proposed. It is based on the simultaneous control of the parameters of the technical condition, mode and operating conditions of the tested component, the division of the ranges of possible changes in the parameters of the mode and conditions at narrow intervals, the formation of possible combinations of the intervals obtained and registration of the standards of the estimated parameter for each combination of intervals at the beginning of operation of an unmanned vehicle. The proposed method is intended for the implementation of the onboard local network of an unmanned vehicle.

1. Introduction

On the way to unmanned driving, not only the technology of automatic control of vehicles, new actuators, sensors, control units, and steering and braking control algorithms, but also automation of the performance monitoring of an unmanned vehicle (UV) are needed [1].

A single failure of any component of modern vehicle with a driver leads to an accident only in extremely rare cases, and in the absolute majority only in combination with the simultaneous impact of other adverse factors (for example, a combination of slippery pavement at the round-off of turning a road on a slope and error the driver in choosing a speed with a tire break in the front wheel).

If the protection of UV against malfunctions is not provided for unmanned traffic, then the multitude of failures of the most diverse components of the traffic control systems, tires, wheels, and even power supply will multiply increase the risk of accidents and unnecessary operational costs.

As a means of protection, control should be provided in the process of road traffic, and not only at service and operating enterprises [2]. This requires the design refinement of the vehicles themselves and control algorithms for their operation. The onboard local network of UV will have to acquire the functions of the driver to monitor the performance and adjust modes or stop driving depending on the technical condition of UV.

The transition to unmanned driving is real only under conditions ensuring the speed and safety of traffic not lower than when the vehicle is operated by drivers [3]. For such a high efficiency of
unmanned driving, its support functions are needed that automate the fulfillment of regulatory and new prescriptions for road vehicle:

1) traffic regulations code;
2) a set of commands for traffic control means;
3) to minimize the damage from traffic obstacles (pedestrians, animals and natural phenomena);
4) to minimize the damage caused by traffic violations by road users, in case of an accident or UV fire;
5) rules of technical operation of the rolling stock of road vehicles;
6) manufacturer instructions for operation (manuals) of UV;
7) to control the operational properties and malfunctions of UV and minimize the damage associated with them.

The last three functions are designed to support not only driving, but also the technical operation of UV. Moreover, if the prescriptions of traffic regulations, Rules of technical operation, commands of traffic regulation tools and manufacturer instructions (manuals) for the vehicle operation, are well structured, formalized and almost ready for algorithmization, then the control of operational properties, implicit failures and algorithms for using control results, minimizing damage from malfunctions, until worked out and brought to clear instructions. The creation of these instructions requires, among other things, the work of the operators.

Transport equipment is subjected to malfunctions. Each vehicle fails many times and is repaired during operation until full depletion. Failures and malfunctions will inevitably be subjected by the means of automatic driving and UV themselves. But if in modern vehicle, the driver subjectively and according to the dashboard readings controls the performance of the vehicle from the beginning of the preparation for departure and to parking, then for UV, this function must first be structured, algorithmized and automated by some means or other. Neither the automotive industry nor the technical exploitation of automobiles has ready solutions for this [4].

By definition, the performance is the state of an object in which the values of all parameters characterizing the ability to perform specified functions corresponds to the requirements of regulatory and (or) design documentation according to Russian State Standard GOST 27.002-2015. In other words, an object is able to perform “specified” functions. But in relation to the vehicle, neither in the operational nor in the design documentation is installed neither a list of “specified” functions of the vehicle nor a list of parameters that characterize the ability to perform these specified functions. The division of functions into basic ones, determined by the purpose of the vehicle, and auxiliary or service functions, which can be referred to as “specified”, is not established either. For example, does the number of "specified" functions of the vehicle include the performance of the cigarette lighter or the mechanism of lifting the hatch in the roof of a car?

Modern vehicles, which include motor vehicles, endowed with dozens and hundreds of functions. Therefore, for a legally significant definition of the nomenclature of “specified” functions of vehicle, it is necessary to refer to the operational documentation - instructions and operation manuals. But they do not have a clear list of vehicle functions.

In civil aviation, aircraft manufacturers and operators develop manuals for engineering and technical personnel and flight crews that establish the airworthiness requirements of the aircraft. They contain "lists of the minimum equipment" of the aircraft that necessary for its admission to flight. Each component of the equipment, depending on the criticality of its failure, is assigned in the list the status of “allowed”, “allowed with time limits” or “not allowed”. In road transport, there are no such lists neither in the transport enterprise nor at the car repair shop, and manufacturers provide for informing drivers through the dashboard only on a limited nomenclature of the most dangerous failures of the internal combustion engine, ABS, SRS (Supplemental Restraint System in vehicles), requiring immediate cessation of movement according to Technical Regulations of the Customs Union "On the safety of wheeled vehicles" № TR CU 018.2011. For the rest of the failures and malfunctions, the Russian and foreign vehicle designs provide only informing about the occurrence of malfunctions (“errors”) without any recommendations to the driver.
For the organization of unmanned traffic, it is necessary to develop and include in the operational documentation a nomenclature of significant functions of UV, lists of allowed, non-allowed and allowed with restrictions of malfunction lists. But first it will be necessary to make the preparation of such prescriptions by manufacturers mandatory. At the same time, the performance of UV, as well as the aircraft, will be determined by the ability to perform only a limited nomenclature of functions previously assigned to the “specified” number. Operational documentation will not attribute the violations of the other functions of UV, as well as of aircraft, to violations of performance and will allow continued operation with these malfunctions (probably with limitations). This will serve to protect unmanned driving from the consequences of malfunctions and failures of UV.

To implement the proposed protection, it is necessary to develop component performance monitoring and design protection control algorithms of UV in the interests of technical operation [5]. In modern UV, the driver, using the dashboard and controls of the backup (emergency) operational systems, carries the function of such protection. In UV, such protection must be automated with software and design tools of the onboard local network [6]. Results will be required before designing control systems and preparing their production. This work aims to substantiate the methods of automating the monitoring of UV performance parameters and the construction of UV protection control algorithms in the interests of technical operation.

2. Material and methods
The necessary development of monitoring the performance of the mechanical and electronic components of UV can be represented by the following set of onboard local network functions for modern UV (Figure 1).

Let’s consider these functions sequentially.

Tracking the execution of commands by the control actuators of the operation systems (ABS modulator valves, electromagnetic relays and steering solenoids, throttle valves, etc.) is used to monitor the performance [7]. In modern vehicles, this is not fully ensured, for example, for ABS modulator valves. Instead of electromagnetic relays in a number of industrial products, intelligent keys are mastered. They additionally have the function of monitoring their own performance. But in the electronic control units in vehicles, they are not yet used instead of the relay.

In UV, the dashboard is not needed, but the functions for monitoring the performance of its readings should be automated. For this purpose, standards of limits of the aggregate parameter changing and vehicle systems, which manufacturers have in full measure, are required [8].

The control and automatic calculation of the parameters for controlling the start-up of the internal combustion engine and the volume of fuel tank refueling (charging traction batteries) have already been worked out for vehicles and, after testing and modifications, can be transferred to the operation of UV [2].

The listed 4 tasks are solved through the experimental design work by the automotive industry in its traditional field of activity.

But the functions of monitoring the operating properties, the performance of components and the corresponding parameters (vibrations, knocks, impacts) of vehicles that are not yet automated and on modern vehicles are sub-objectively carried out by drivers while driving and mechanics before repair, have to be transferred to the control systems of unmanned driving [8]. Automation of these functions is impossible without preliminary implementation of research with the participation of scientific forces of exploitation.
For the safe and economical operation of UV, it is necessary, in particular, to automate the control directly in the process of road traffic of changing operational properties (brake, traction-speed, fuel efficiency, safety). For this, individual technical proposals have already been developed [9]. Thus, the condition for the implementation and an integral component of the algorithms of unmanned driving is the automatic control of the operational properties of UV, from which depends the economic feasibility of continued operation and driving safety. Modern vehicles are not equipped with automatic means of controlling the operational properties. Drivers are forced to subjectively evaluate their deterioration, relying only on our experience and not having the technological control capabilities either while driving or preparing for departure. Only at car repair shops (CRS) or transport enterprises (TE), the mechanic have the ability to monitor the performance of the vehicle using technical means.

The methodology for the automatic monitoring of UV operational properties is illustrated by the development of a service to control the traction-speed properties of vehicles [9] performed by MADI in 2019. It is intended to automatically control the development of malfunctions that decline the dynamics of acceleration, and reduce the duration of operation with malfunctions. The control is proposed to be performed by means of the onboard local network according to the acceleration time in specified narrow speed intervals directly in the process of road traffic. For this, the measured acceleration time is compared with one of the standard values previously established for each set of significant influencing factors. The set of significant factors and parameters characterizing these factors was established in a preliminary performed study. The service generates and registers regulatory values automatically at the beginning of operation and updates as wear and after each engine change. The service is implemented algorithmically, using software, without additional equipment of vehicle with sensors or other additional components.

The service uses signals read from the local network of the vehicle:
- fuel control sensor signal;

**Figure 1.** Functions of the onboard local network for monitoring the UV performance.

- Monitoring functions
  - Requiring research with the participation of the operation of road
    - operational properties of UV
    - Control of the appearance of vibrations, knocks, gnashing, shocks on UV
    - Monitoring the UV component performance, not automated on modern vehicles
  - tanks (battery charging), calculations of the power reserve and refueling volume
  - Control and calculation of engine start control parameters

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The service uses signals read from the local network of the vehicle:
- fuel control sensor signal;
vehicle load sensor signal;
outdoor temperature sensor signal;
pavement status sensor signal;
vehicle speed signal.

A generalized block diagram of the control algorithms for UV traction-speed properties is shown in Figure 2

The developed algorithms were experimentally tested on a passenger car, and technical proposals for substantiating initial requirements for a new service were prepared on their basis.

**Figure 2.** The block diagram of the control algorithms for traction and speed properties of UV.

Certain difficulties will be presented by the solution of the actual for UV problem of automating the control of the associated parameters of the technical state, which drivers of the vehicles perceive and evaluate subjectively. In modern vehicles, there are no means of their control. Vibrations, knocks, gnashing, crunching, impacts, aggregates heating, which are not typical for the normal functioning of vehicle, serve as such parameters. To minimize the consequences of malfunctions and failures in the driving process, these are very important sources of information. They allow the driver to react on failures in a timely manner, minimize or prevent damage from them, and avoid chain development of malfunctions.
However, in road transport, there are almost no developments in this direction, as well as ready-made technical solutions for transferring to the UV control systems. For this, automobile manufacturers will need to borrow experience of the most advanced branches of technology. For developers of unmanned driving systems, this is a task for the near future.

For on-line correction of unmanned driving algorithms in case of UV malfunctions, control of their most critical components is required. It is most relevant to automate the control of those components that are absent in modern vehicle.

Automation of performance monitoring of UV components will be considered depending on the consequences of their malfunctions. First of all, the control needs to cover the components, the failures of which are capable of causing an accident. These include suspension assemblies, changes (for various reasons) of tire adhesion to the road surface, pressure (and in the long haul - temperature) of tires, brake linings and fluids, light-signaling devices, etc.).

From the standpoint of resistance to the ultimate reliability of vehicle, including unmanned vehicles, it is advisable to introduce the following division of malfunctions:
1) impeding opportunities or motion control (failures);
2) predictable, gradually developing until failure;
3) worsening operating properties of fuel economy of braking or traction dynamics;
4) causing a vehicle non-compliance with safety requirements or unacceptable for its economical operation.

This classification ranks UV malfunctions on the basis of uniformity of methods for monitoring their appearance and development. Thus, the automatic identification of failures that impede the movement of UV will not cause difficulties. For this, instead of monitoring the technical condition of the components, it is enough to control signs of failures. They are identified algorithmically by combinations of fixed violations of the correct functioning of UV. The algorithms used for this not only identify failures, but also, taking into account their consequences, form control commands for adaptive cruise control systems. These systems consistently increase their capabilities and are already widely used by manufacturers in modern vehicles [7].

Automation of the control of the gradual development of faults that impede driving or leading to road failures has not yet received such a development due to less damage from their effects on the vehicle. But for UV, it will be fully demanded. Proposals for methods of controlling the gradual development of malfunctions and algorithms for using the results to predict the residual life of units and assemblies have already been developed by the scientific forces of operation [8].

Automating the monitoring of the fault development that impair the safety or economy of UV operation remains the least developed task. It should be solved both for the “traditional” and for the new components of UV. New will be high-tech components that distinguish UV: near and mobile radio modules, motion control, numerous batteries, new sensors and actuators. In addition to methods for monitoring their performance, the requirements for resources and redundancy should be worked out, at a minimum, for those components of UV, the failures of which significantly increase the probability of an accident. The nomenclature of these components is also to be justified. There are no ready technical solutions, requirements and lists.

To monitor the performance of a vehicle component, one or more parameters may be required. In the latter case, for convenience of control, the estimated indirect parameter derived from the directly measured, for example, specific fuel consumption, specific braking force and power given to the load of the battery, is usually calculated. Therefore, similar to measurements, it is advisable to divide control methods into “one-parameter” (direct) and “multiparameter” (indirect) control.

Depending on the presence of bilateral or unilateral upper or lower limits for the estimated parameter of performance, the standards (tolerances) are introduced under control.

Applied estimated performance parameters should be subdivided according to the presence or absence of dependence of their standards on operating modes or operating conditions of the controlled component of the vehicle. These modes and conditions are characterized by their “regime” parameters.
For example, the pressure in the tires depends on the temperature, so the pressure control is performed with the cooled down tires.

One-parameter control by performance parameters, independent of the operation mode of the vehicle component, is methodologically the simplest one. It uses fixed unilateral or bilateral standards established by the manufacturer or technical regulations. So they control brake linings, valves of modulators, the level and temperature of brake fluid, light-signaling devices and door opening mechanisms in buses. When a command is received to turn them on or check (with the frequency of its receipt), a predetermined delay is counted and the actuation sensor of the tested node is called. If the sensor signal does not match the specified value, a single node failure is registered.

This is the simplest type of control performed with minimal frequency. Methods of monitoring for performance parameters, depending on the mode of the component operation or the operating conditions of the vehicle, are much more complicated. If it is impossible to level this dependence by organizational measures, as is done when checking of the tire pressure or smoke measuring only when the diesel engine is warm, it is necessary to create more sophisticated control procedures.

For the parameters of engine oil pressure, battery charging, fuel consumption, acceleration dynamics and braking efficiency, a control method has been developed taking into account their dependence on the operating mode, the main stages of which are formulated as follows.
1. The simultaneous control of the technical condition parameter and parameters of the operation mode of the component under test.
2. The division of the ranges of possible changes in the parameters of the mode at narrow intervals.
3. The formation of possible combinations of the obtained intervals of mode parameters.
4. The formation of a set of standards for the estimated parameter for each combination of intervals.
5. The use of standards for the limiting values of the estimated parameters that set by manufacturers in the repair and maintenance documentation and the requirements of regulatory documents on the safety of vehicle.
6. Registration of the required for predicting of the resource initial values of the technical state parameters at the beginning of operation of each UV separately for each combination of mode parameter intervals.

This technique was implemented, in particular, in the aforementioned service for controlling traction-speed properties of vehicles [9].

Along with the automation of motion control [10, 11] and monitoring the component performance of UV [12], the addition of unmanned driving with a package of auxiliary restrictive and service algorithms for the automatic control of UV to rationalize their technical operation will be equally relevant [13]. Among them are the algorithms:
- UV automatic refueling (charging);
- automatic start of internal combustion engine;
- generalization and evaluation of the monitoring results of the UV component performance and making decisions on the possibility of continuing the movement;
- emergency stops on the road sections of different category, different profiles and facilities;
- the formation of data packages on the performance of UV for motor TE and CRS.

The preparation of these algorithms will also require preliminary research to study and summarize the available data on the options of their implementation for different operating conditions, for UV of different design schemes, configurations and purposes.

In conclusion, it should be noted that the implementation of the proposed functions of monitoring the component performance and UV operational properties is most appropriate for onboard measuring instruments and a local network. Their transfer to the information systems of motor transport enterprises and regional traffic control centers will not result in any reliability or speed of passing control commands. The proposed solution will not affect the degree of UV traffic control autonomy and the separation of driving functions between the distributed information environment of road transport and the local network of UV.
3. Results
Protection of modern vehicle against the consequences of failures and malfunctions is provided by the
driver. For the transition to unmanned motion, this driver function will have to be automated
beforehand.

However, in automotive designs, there are very few means for monitoring the performance of even
the most critical components and for algorithmic protection against the consequences of malfunctions.
In a vehicle, electrical parameters of functioning and single parameters of mechanical components are
mainly controlled.

For the required expansion of the vehicle component coverage with automatic performance
monitoring, the simplest one-parameter control is not enough. It will be necessary to develop methods
of indirect performance monitoring based on a set of functioning parameters and operating modes of
the component being tested.

The most rational implementation of the proposed methodology for such indirect control may be
the use of the capabilities of the UV onboard local network, standard and additional sensors specially
included in UV design.

4. Discussion
The above argument convincingly demonstrates the relevance of the development of technical
measures to protect unmanned driving from failures of UV components. The transition to unmanned
driving without first creating its protection against failures of UV components will lead to a multiple
increase in the risk of accidents and operational costs.

In modern vehicles, only the most primitive algorithms of one-parameter tolerance control are
implemented. They are not applicable to indirect monitoring of the operational properties of UV and
their components with calculated evaluation parameters depending on both the technical condition and
the modes and operating conditions of the checked components of UV. For their control, new methods
are needed that take into account the multifactorial variability of the estimated parameters in the UV
functioning. Such an approach is implemented by the proposed method of indirect control of the
component performance and the operational properties of UV. Its advantage is the automation of all
control operations and the use of its results to correct driving of UV. The proposed method can be
used to control other technical objects outside the road transport.

The development of the presented approach to automatic indirect control can be research on the
methods of substantiating the initial and limiting standards for the UV performance.

5. Conclusions
Protection of unmanned motion from the consequences of failures and malfunctions of their UV
components through the development of control and adjustment of motion control algorithms remains
unrealized in automotive structures and design activities. However, until this seemingly secondary task
is solved, the transition from vehicle to UV will not be implemented in practice.

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