Development approach to a method for monitoring of driver’s ability of resumption of control over the vehicle by on-board systems in automatic mode

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Abstract. The structure and basic functionalities of the upper level on-board information-analytical system and its link-up while simultaneous use with other intelligent on-board systems on the vehicle’s board are studied. A development approach to a new method for estimating the potential for the transition (resumption) of driver’s control over the vehicle by on-board systems in automatic mode, presumably having high efficiency and reliability, is proposed and justified.

Key words: ADAS, on-board intelligent systems, detection of hazardous driving conditions, vehicle, driver’s functional state, vehicle automation level, resumption of driver’s control over the vehicle.

Introduction

The widely known classification system of Levels of Driving Automation for On-Road Vehicles was developed by the Society of Automotive Engineers (SAE J3016 standard [1]). It contains 6 levels:

Level 0 (No Automation): no automatic control over the vehicle, but a warning system can be available; the full-time driving performance is carried out by the human driver.

Level 1 (Driver Assistance): the human driver mostly performs the driving; as a rule, Advanced Driver Assistance Systems are installed on the vehicle’s board assisting the driver in steering and braking systems control using the information about the driving environment. They work in automatic mode, but can be disabled by the human driver.

Level 2 (Partial Automation): the human driver must react if the system fails to perform in the automatic mode. ADAS simultaneously controls acceleration, braking and steering, but can be disabled by the driver.

Level 3 (Conditional Automation): the human driver may not control the vehicle on some types of roads (for example, autobahns), but should be ready to resume control when changing the traffic conditions or the system stops the vehicle if the driver does not respond to the alert.

Level 4 (High Automation): it is similar to the 3rd level, but does not require the driver’s attention and performs its functions permissible in specific external driving conditions.
Level 5 (Full Automation): no human intervention is required except for indicating the start of the driving and determination of destination.

The classification presented shows that right from the Level 1, on-board systems are hardware-software tools where a significant place (including in functionality) have the methods and algorithms for analysis of heterogeneous information on the functioning processes of vehicles and synthesis of control actions on different hierarchical levels systems for vehicle stability control and vehicle trajectory movement using IT methods and technologies and specialized software (the degree of automation increases at each Level), and only at the Level 5 no action is required on the part of the human driver except for indicating the start of the driving and determining the destination.

Figure 1 shows the vision of Movement company [2] on the current software “volumes” (one of the simplest characteristics of the metrics is the lines of code number) in different systems, in comparison, and how the “todays”-car will be changed in the future.

![Characteristics of software metrics](image)

![Change in vehicle value from hardware to software](image)

Figure 1. The number of lines of code in different systems and the volume of technical components, software and content in road transport in the future [2].
Thus, the level of automation of the vehicle significantly increases, while the stage of equipping a vehicle with ADAS systems is considered as an intermediate stage when moving to fully automated traffic mode. According to experts, by 2035 on the general use roads of the Russian Federation there will be about 10% of unmanned vehicles. Compromise options will be implemented, when the vehicle drives automatically under the specified conditions, and when the conditions change (primarily associated with the complexity or inability to formalize it) it “transfers” the control over the vehicle to the driver.

Classification of methods for driver fatigue monitoring

There are basic requirements for the systems of monitoring of the functional state of “human-machine” systems’ operators [3,4], including vehicle drivers. One of these requirements is to identify the signs of hazardous states and to interpret the real-time functional states incompatible with the task performed (death, loss of consciousness, sleep, etc.). Detection of the hazardous states signs allows taking preventive measures in unmanned or automated mode, while statement of the presence of such functional states almost inevitably leads to emergency situation developing.

There are some methods for determining indications of sleep and deep relaxation of vehicle operators(Table 1, where \( p \)– the probability of a hazardous failure, EDA – electrodermal activity) to be the basis for many driver fatigue monitoring systems [5].

Table 1. Methods determining indications of sleep and deep relaxation [5].

| Vigilance estimate technology                  | \( p \) |
|-----------------------------------------------|---------|
| Changing the driving “style”                  | 0,3     |
| Rational actions                              | 0,3     |
| Pulpus                                        | 0,3     |
| Posture (muscle tonus)                        | 0,2     |
| Glance direction                              | 0,2     |
| Head tilt (muscle tonus)                      | 0,1     |
| Speech                                        | 0,1     |
| Oculography                                   | 0,05    |
| Blinking                                      | 0,02    |
| Microsaccades (optional)                      | 0,001   |
| EDA (72mln man-h without accidents)           | 0,0001  |

Development of upper-level information-analytical system

Fig. 2 demonstrates the structure of the upper level on-board information-analytical system (BIAS) and its link-up while simultaneous use with other intelligent on-board systems on the vehicle’s board [6]. The main purpose of the system is preventive automatic prediction of an emergency situation, including those caused by erroneous driver’s actions or automatic interpretation of driver’s hazardous states (not compatible with the implementation of the basic algorithms for driving a vehicle), in real time, by keeping the vehicle in the traffic lane (with the use of active safety systems serially produced by OJSC “Ekran”, systems of electromechanical power steering system for monitoring dead zones around a moving vehicle developed in Belarus, an electronic-pneumatic brake drive system, an adaptive cruise control system in the future), using classical passive ADAS potential (for example, Mobileye 6-Series), with adjustments, if necessary, of the trajectory movement of the vehicle using information from a high-precision navigation module. The BIAS fulfills the functions of the system integrator (depending on the on-board systems installed on a particular vehicle), reduces kinetic energy and/or stops the emergency mode of the vehicle if the driving conditions are appropriate, taking into account the integrated assessment on the basis of analysis of information from all the connected on-board systems from the unified methodological positions. In case of an accident occurrence, the BIAS implements automatically the function of emergency response systems in case of accidents (ERA-RB, ERA-GLONASS).
The on-board module for detection of driver’s hazardous states is connected to the system via CAN bus [5, 6]. Application of the module significantly expands the functionality of the BIAS and gives the system the properties of a preventive safety system that secure from the occurrence of an accident because of deep relaxation, loss of consciousness or death of the driver. The module has some distinct advantages while it has a specialized chipset, robust algorithms for extracting a useful signal from the noise, original algorithms for automated interpreting of the driver’s functional state, near telemetry for transmitting information to the stationary part of the system, which makes it possible to obtain high reliability of interpreting the dynamics of the driver’s vigilance level comparable to the requirements specified for active safety systems. The prototype for the module being under development is a serially produced driver vigilance telemetric control system or VIGITON, which uses monitoring and automatic analysis of the parameters of electro dermal activity (the main criterion for automatic interpretation of the current dynamics of the driver’s relaxation level, the method used has the smallest known probability of a dangerous failure ($p \approx 0.0001$), the concepts of building the driver’s state safe monitoring systems are applied. The on-board module technical specifications for detection of driver’s hazardous states (deep relaxation, loss of consciousness, death) contain the dangerous error probability of the registration method ($2^{\text{nd}}$ kind error) of no more than $4 \times 10^{-4}$ and the probability of dangerous failures leading to accidents of no less than $10^{-9}$.

**Figure 2. The BIAS structure and its link-up on the vehicle’s board**
The navigation module. GLONASS (L1, L2 frequency bands), GPS (L1, L2 frequency bands), GALILEO (E1B, E1C, E5a, E5b frequency bands) and BEIDOU (B1-C range) are used to improve the accuracy and reliability of the navigation module. The RTK technology (Real Time Kinematic) is provided for possible use for further improvement of position determination accuracy, which allows obtaining of centimeter accuracy of position determination due to the simultaneous processing of signals from GNSS and signals of correcting stations in real time [7]. The ability to integrate GNSS signal processing with the information from sensors of micro electromechanical systems and the odometer sensor of the vehicle’s path allows using the “Dead reckoning” technology, which provides diminishing of the error in calculating of navigation parameters and allows position data assessment when the GNSS signals are inaccessible in the specified time spans. The module supports automatic monitoring of the integrity (accuracy) of navigation definitions and deletion of unreliable measurements, implementation of differential correction robust algorithms (RTK mode) and algorithms for integrating GNSS data and inertial sensors (accelerometers) of Belarusian design, determining navigation parameters in WGS-84 or PZ-90 (with a confidence level of 0.95).

The basic module contains the necessary hardware and a set of interfaces providing implementation of basic functions and technological modes.

The extension module has the additional functionality related to interaction with advanced intelligent systems installed on the vehicle’s board.

The BIAS software has a multi-level modular hierarchical structure. Individual modules operate asynchronously with respect to each other, which allow realizing multi-tasking mode of operation in real time. The file structure used provides maximum isolation of the levels code and modules.

**Research methods for the transition of vehicles from “automated” driving mode to “manual”**

Until now, research methods for the transition of vehicles from the automated driving mode to the “manual” one stand at the beginning of development and are at the stages of “search” and research projects [8, 9, etc.]. The overwhelming majority of research projects use the methods for monitoring and evaluating the driver’s visual analyzer dynamics applying appropriate experimental equipment in interrelations with the regaining of driver’s control over vehicle’s trajectory movement, situation conditions and performance of algorithms (or their fragments) in different variations and in real time with the vehicle automation levels from the first to the fourth according to the SAE’s levels of driving automation.

It was found that depending on the specific traffic conditions, the tasks the driver was engaged in before the circumstances for resumption of the driving control arose (e.g. passive observation of the traffic situation, various telemetric services use, information on DVD media viewing), the driver will need some tens of seconds to regain control over the vehicle. But it indicates that “further research should identify how to inform the drivers in the best possible way of their commitment to resume control over the automated vehicle”.

One of the common options can be a request from the driver for his readiness to regain control over the vehicle driving. The driver’s subjective response is significant, as he/she clearly understands that the positive response gives him/her the entire measure of responsibility, including the responsibility for the road safety. Table 1 shows that ADAS of DMS reliability of the interpretation of the driver’s functional state (driver’s state control system) is classified according to the technology used in the particular DMS, and the probability of a dangerous failure lies in the range \( p \approx 0.001 \), using the methods of monitoring the driver’s visual analyzer and \( p \approx 0.0001 \), using methods of monitoring the analysis of EDA dynamics with automatic interpretation of the driver’s functional state (the ability to perform specified algorithms of activity) of “deep relaxation” type.

The methodology of monitoring of the functional state (the ability to perform the specified operational algorithms in real time, the readiness for emergency action) of “human-machine” transport systems operators, widely approved by locomotive drivers and car drivers [10-13, etc.] and based on automatic analysis of the parameters of the operator’s EDA, is widely known. The systems for maintaining the performance of vehicle drivers have passed qualification tests [14] and continue
developing [3-6].

The on-board module for determining the driver’s hazardous states (deep relaxation, loss of consciousness or death of the driver) is used in the BIAS where automated interpretation of the driver’s relaxation (not compatible with the required readiness to perform the algorithms of driving activity) is based on an automated analysis of the EDA parameters, which provides efficiency and the highest reliability of the proposed approach to the development and investigation of a new method(s) for estimating the potential for the transition (resumption) of driver’s control over the vehicle by on-board systems in automatic mode.

Conclusion

Implementation in the BIAS of the functions of the driver’s functional state monitoring, high-precision determination of the current vehicle navigational coordinates and analysis of heterogeneous current information (dynamic characteristics of the vehicle, the state of the main units and assemblies, driver state, navigation coordinate and its trend) in real time, where original algorithms and software are used, the modularity of the BIAS construction and the possibility of increasing the functionality through integration with other on-board systems has a development perspective and is aimed at improving the efficiency of “human-machine” motor vehicle systems.

The BIAS, being essentially an on-board integrating complex, can also be used as an experimental system to justify and develop the new methods for monitoring the ability of resumption of control over the vehicle by the driver, when the driver is potentially able to perform the required algorithms of activity (to regain control over the vehicle) while transition of control from automated driving to the “manual” one.

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