Cross-modal information flows in highly automated vehicles

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Abstract. The classification of cross-modal information flows in highly automated and autonomous vehicles is presented. The definition of cross-modal interaction in the highly automated vehicles is given and the goal of the analysis of heterogeneous information flows in onboard systems of vehicles is formulated. From the interdisciplinary perspective, on the basis of the system approach, the main provisions of the original method for analyzing the driver's potential to regain control of the highly automated vehicle are formulated. They are based on the driver's awareness of the situational circumstances along the route, monitoring the current functional state and individual driver’s characteristics.

1. Introduction

The level of vehicles automation is incrementally growing. That not only makes it possible to solve the pre-existing problems at vehicles operation but also creates new ones to be explored and solved. With the increase in the level of automation, the volumes of heterogeneous information circulating in such metasystem as “driver – highly automated vehicle – road – intelligent transport system – information field” are growing at a significant rate. Obviously, in this case, the “information field” falls under the category of “Big data”. Figure 1 shows the projected flow of data generated in autonomous vehicles and the main sources.

To implement algorithms of movement trajectory and correct them in compliance with the current terms, the autonomous vehicles, according to experts from Intel [1], need cameras that generate an information flow about 20-60 MB/s, radars and ultrasonic locators (each with 10-100 kB/s), GPS navigation systems – 50 kB/s (although we believe that it is preferable to use four-system navigation chipset GLONASS, GALILEO, BEIDOU, GPS – 50 kB/s for each GNSS, 200 kB/s, as having a functional that allows to determine the current coordinate with greater accuracy, higher noise immunity and reliability [2]), Lidar forms traffic of about 10-70 MB/s. According to approximate expert estimates, a vehicle using such technologies will generate about 4 TB of data per day [1]. To this the information is added generated by the “classic” active security systems and monitoring systems of major joints and units.
A distinctive feature of the multi-system navigation GNSS receiver is that it identifies more signals from different navigation satellite devices. The total number of satellites visible by the receiver can increase essentially (for two system satellites it increases on average by one and a half to two times). Due to this possibility, the multi-segment receiver selects the best geometry by a combination of accompanied satellites, which directly affects the positioning accuracy. Under the conditions of strong attenuation of received signals power due to wide choice possibilities, the receiver can choose the best signal-to-noise signals for the navigation solution, which significantly improves the reliability of navigation. For the same reasons, narrowband interference will not be able to block the signals reception from all systems of the multi-system receiver, which increases the accuracy of positioning in rough conditions of reception, i.e. increases the noise immunity of the satellite navigation receiver. In addition to positioning accuracy due to the multi-system for the same reasons, the time to obtain a fixed solution in RTK mode, which is widely used to obtain high-precision data, is significantly reduced. The multi-system satellite receivers have a higher level of security due to the implementation in the software of an algorithm for monitoring the integrity of data received from navigation satellites. The algorithm is designed to detect anomalies caused by failures of navigation satellites or ground control system. Such algorithms are implemented in single-system receivers as well, however, due to the fact that the multi-system receiver has more source data for this algorithm, the possibility of detecting anomalies is wider. And that allows to identify and exclude from the navigation solution not only individual satellites, but also the whole navigation systems, operating in abnormal modes intentionally or unintentionally.

2. Cross-modal information flows in highly automated and autonomous vehicles
In highly automated vehicles, information flows (IF) of various semantics obtained from intelligent transport systems (to inform the driver), telematics systems, cameras and sensors of monitoring the functional state of the driver are additionally added to these flows, including for solving the problem of automatic assessment of determining the time of possible control transfer to the driver, when the driver is potentially able to perform the required algorithms of activity, when switching from the automatic mode of vehicle movement control to the “manual” one. The autonomous and highly automated vehicles are also a significant consumer of information from the telematics systems (for example, high-precision
3D road maps (including the area at a distance of several meters from them), which will be constantly updated in an automatic mode using the resources of the vehicles, including high-precision navigation coordinates of road marking; the vehicle sends the received data to the “cloud”, where they are converted into a high-precision digital copy of the route of the road, figure 2) and from the evolving communication platform Cellular Vehicle to Everything (C-V2X) for “connected” vehicles and the transition to the use of 5G communication technology. The functionality of C-V2X has significant prospects, as it uses both network (already existing coverage of cellular networks and distribution of smartphones, tablets and gadgets) and “direct” communication used for V2X services. The volume of data flows received by the highly automated and autonomous vehicle is commensurate with the amount of data generated by the autonomous vehicle.

![Figure 2. Fragment of a high-precision 3D roads map [3].](image)

2.1. Definition
The cross-modal interaction in highly automated vehicles is the transformation, synchronization and analysis of heterogeneous information flows in onboard vehicle systems in real time, with a single target function.

The purpose of the analysis of heterogeneous information flows in the vehicle onboard systems is to obtain an integrated assessment (synthesis of integrated evaluation criteria) and automatic development of control commands for efficient operation in highly automated driving (HAD) with support of ADAS and intelligent transport systems (ITS) in real time.

One of the priority areas is automatic monitoring and analysis of the fleet of connected vehicles, including the exchange of information. This will make it possible to identify and block emerging threats in a timely manner.

2.2. The main problems of the “human factor” arising in the operation of the highly automated vehicles
It is known that with the growth of automation in all classes of “human–machine” systems, there are more and more monotonous fragments in the algorithms of human-operator activity, which have a negative impact on the “regular” implementation of the activity algorithms, primarily reduce the current awareness of the integrated situational circumstances (which affects the adequacy of the assessment of the dynamics of its development) and increase the reaction time of the human-operator in case of the...
need for emergency action, which directly affects the safety of the functioning of the “human–machine” systems. This also applies to the drivers of the vehicle with the HAD.

It is known that the use of ACC leads to a relatively small reduction in the workload of the driver, and the HAD leads to a significant reduction in the workload compared to manual driving. The paper [4] presents an overview of the experimental data obtained in twelve studies on the effectiveness of solving additional tasks by the driver when using the ACC and the HAD under load and on awareness of the driver's situation in comparison with manual driving. The analysis of the working load measured as efficiency at performance of the arbitrary task displayed on the onboard display is given as well. The average number of tasks completed was 100% for manual driving, 112% – when using the ACC, and 261% – when using the HAD. Stated differently, using the ACC, drivers can perform approximately 12% more tasks on the visual display than with manual driving. However, when using the HAD, drivers can perform more than 2.5 times more tasks than with manual driving. More than 4,000 literary sources were subjected to meta-analysis.

About twenty years ago, studies of the problem of “human factor” with the increasing level of automation in the vehicle, mainly focused on the interaction of the drivers with the ACC, were started, and even then it was found that an increase in the level of automation can lead to a decrease in drivers’ awareness of the road situation, contributing to a decrease in the efficiency of the implementation of algorithms for handling the vehicle in case of emergency situations [5]. Subsequently, similar results were obtained in the study of the influence of the ADAS maintaining the lane on the driver at the levels of automation of the vehicle from the first to the third.

The presented results indicate the relevance of the task of monitoring the driver’s functional state (the potential ability to perform the required algorithms) in real time, including when using the HAD, including for prevention of the onset of driver relaxation, the level of which has a negative impact on the readiness for emergency action. The activation time of functional driver systems is by times higher than the response time of onboard systems.

3. The main provisions of the analysis method of the driver’s potential to regain control over the highly automated vehicle

Development of evaluation criteria and conditions for automatic transition of control to the driver on the move, when changing the paradigm of the vehicle control from automatic to manual, is one of the most urgent tasks today. The main task is to determine at what point in time the safe transition of control to the driver is possible, when the driver is already potentially able to perform the required algorithms of activity in accordance with the current functional state. Obviously, for different drivers this time will be different, because various internal and external factors having different weight coefficients exert influence. Basic ones are awareness of the situational circumstances along the route, the current functional state (largely due to the nature of the driver’s activity in the previous 5-10 minutes) and the individual characteristics of the driver.

Situational circumstances along the route are the quality and variable value, depending on many factors (traffic intensity and potential difficulties on specific local road sections, emergency situations, incidents and accidents, weather conditions, time of day, etc.). The studies on the driver's awareness of the situational circumstances along the route are conducted in the world quite intensively [4,6,7, etc.]. According to various estimates, and depending on the complexity of the situation and the type of the driver’s activity in the previous time, the driver takes from a few tens of seconds (often about 60 seconds) to 360 seconds to adequately assess the situation. The majority of research projects use methods of monitoring and evaluating the dynamics of the visual analyzer of the driver, using the appropriate experimental equipment, in relation to the restoration of driver’s control over the motion trajectory of the vehicle, the situational circumstances and the implementation of algorithms of activity (or their fragments) in different variations and in real scope of time. Directly during the restoration of awareness of the situation, the dynamics of changes in psycho-physiological and physiological parameters of drivers is of particular importance.
Methods of monitoring and maintaining the current functional state of the driver on the basis of monitoring and analysis of electrodermal parameters of the driver in connection with the performed algorithms of activity, directly during the execution of the algorithms of activity, are developed and repeatedly tested, and the systems that implement them are produced in quantity. It is found that they ensure the maintenance of the driver in a state of readiness for the emergency action [8-11, etc.].

Individual features of the driver, in this context, is primarily the dynamics of psycho-physiological (physiological) parameters, the level and dynamics of its professionally important qualities (PIQ) for the controlling the vehicle. The PIQ of a specific driver, including individual quantitative values (for example, the time spent on the implementation of control actions, receiving signal information), some of which are in the databases of systems of professional selection and development of such qualities. For example, the paper [12] presents an approach that allows the operator (driver) to control the perception of semantically binary relevant information. The most widespread system of professional selection of drivers are hardware and software complex automobile “Universal psychodiagnostic complex” (UPDK-MK) [13] and “Psychological certification of drivers” (VIENNA testing system) [14], that use about 30-50 psychological techniques, psycho-physiological parameters and personality tests to assess the level of the PIQ of drivers in stationary conditions during the professional selection or inspection. For example, the UPDK-MK provides testing of psycho-physiological PIQ (perception of spatial relations and time, eye estimation, stability, switchability and distribution of attention, memory, psychomotor, emotional stability, dynamics of performance) and the properties and qualities of the driver's personality, which make it possible for him to drive safely (neuro-mental stability, temperament properties, risk tolerance, proneness to conflict, resistance to monotony). The UPDK-MK also includes methods of development of PIQ (training of selectivity and concentration, attention distribution, increase of emotional stability, flexibility of actions rate, resistance to monotony) and methods of the general development (training of associative processes, memory on images and symbols). All methods used in testing the PIQ are valid. Information from the databases of professional selection systems or inspection of a particular driver can be available for the ITS and using the information channels C-V2X, on the board of the highly automated vehicle with this driver, and can be used in the analysis algorithms of the potential of the driver to regain control over the highly automated vehicle, to improve their reliability. Some values of professionally important parameters can be updated in automatic mode, for example, all that is associated with the reaction times of the drivers during the “manual” control [12].

4. Conclusions
The classification of the cross-modal information flows in the highly automated and autonomous vehicles is presented. The definition of the cross-modal interaction in the highly automated vehicles is given and the goal of the analysis of the heterogeneous information flows in onboard systems of the vehicles is formulated.

From the interdisciplinary perspective, on the basis of the system approach, the main provisions of the original method for analyzing the driver's potential to regain control of the highly automated vehicle are formulated. They are based on the driver's awareness of the situational circumstances along the route, monitoring the current functional state and individual driver’s characteristics.

The development of the ITS, ADAS, active safety systems (including high-precision navigation modules, working with multiple GNSS) and steadily increasing level of the vehicles automation make it possible to formulate and solve entirely new problems for the safe functioning of “human–machine” transport systems, and the automatic analysis of the heterogeneous information streams gives a synergistic effect. The cross-modal interaction in “human-machine” transport systems is the interaction of hierarchically ranked multi-functional onboard systems of monitoring and control (the technical components of the vehicle, characteristics of the movement trajectory in relation to a navigation coordinate, the results of the work of the ADAS, including the functional state of the driver) between them and external systems (primarily: the ITS, traffic control and emergency services) with objective function of increasing the efficiency of the “human-machine” systems. Analysis of the cross-modal information exchange in the “human-machine” transport system with a single methodological position...
will make it possible, with precision acceptable for the solution of applied tasks, to form in the real time an integrated assessment of the status of basic components of the “human-machine” system and the dynamics of changes in the situational circumstances in the relationships, including external environment.

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